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Controller Productivity
in the Upgraded Third Generation
Air Traffic Control System

Part II: Automation in the Data Link Era

FEISAL S. KEBLAWI

AUGUST 1976

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Controller Productivity in the Upgraded Third Generation Air Traffic Control System

Part II: Automation in the Data Link Era

FEISAL S. KEBLAWI

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ABSTRACT

This document is one of two reports which were prepared to provide the latest estimates of the expected increase in productivity of en route and terminal area air traffic controllers, due to the implementation of the Upgraded Third Generation control system. Part I addresses the automation improvements in the pre-data link era. Part II addresses improvements in the data link era. The benefits due to the implementation of these automation programs are discussed in detail and transformed into dollar savings.

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EXECUTIVE SUMMARY

INTRODUCTION

In 1971, the FAA published its first report* on the increase in controller productivity which might be expected as a result of implementing the Upgraded Third Generation (UG3RD) Air Traffic Control (ATC) Automation programs. In the fall of 1974, the Department of Transportation, in its staff study of the UG3RD** ATC System, asked the FAA to reassess the expected benefits of the UG3RD including its impact on controller productivity.

This document is one of two reports which have been prepared to provide the latest estimates of the expected increase in productivity of en route and terminal area air traffic controllers due to the UG3RD program and to be responsive to the DOT request of 1974.

The first report*** (Part I) addressed the increased productivity expected to be achieved as a result of those UG3RD programs which are scheduled to be available in the pre-data link era (1976-1985). This document (Part II) addresses those improvements expected to be achieved when the data link is available as a result of the Discrete Address Beacon System (DABS) program and when advanced automation has been developed for the automatic generation of ATC messages. Both reports assess the potential benefits beginning with the implementation of the improvement programs to the year 2000.

The main reason for publishing the productivity study in two parts was the desire of the FAA to place emphasis on the fact that there is a substantial difference in the confidence that can be placed on the productivity expected in the pre-data link era. The improvement programs discussed in Part I (or the pre-data link era) are reasonably well defined and there is reasonable

*

Rucker, R. A., et al., "Controller Productivity Study," The MITRE Corporation, MTR-6110, Washington, D. C., November 1971.

** "Review of the UG3RD ATC System Development," a Department of Transportation Staff Study, August 1974.

*** Keblawi, F.S., "Controller Productivity Study in the Upgraded Third Generation Air Traffic Control System, Part I: Automation in the Pre-Data Link Era," The MITRE Corporation, FAA-EM-76-3, Washington, D. C., July 1976.

confidence that the forecast increase in controller productivity from these improvements can be achieved or even exceeded. The improvements applicable to the data link era are substantially less defined and there is still a great deal of uncertainty as to what their impact on productivity will actually be. The discussion in this document (Part II) regarding the productivity increases considered possible with those advanced improvements should be viewed as the best judgement that can be made at this time.

The approach utilized for obtaining the projected staffing requirements was based on utilizing the FAA mathematical models whenever possible. However, since staffing requirements in different size terminal facilities will differ depending upon the improvement programs implemented in those facilities, it was necessary to develop a staffing model that provides separate staffing projections for the different types of terminals that comprise the terminal ATC system. This model (described only briefly in this document) and the productivity associated with the pre-data link automation programs were discussed in detail in Part I of this report. The reader is thus referred to Part I of the report for the details on the approach to staffing projections and for the derivation of staffing requirements in the pre-data link era.

ADVANCED AUTOMATION IN TERMINAL FACILITIES

In the data link era, the following features of Advanced Automation in the UG3RD are expected to have significant impact on controller productivity in the terminal facilities:

- Automatic Generation of Routine Control Messages
- Automatic Delivery of Control Messages via Data Link
- Advanced Metering and Spacing (Multiple Runway and Departure)

In the terminal system, a significant portion of all control messages in terminals are related to Metering and Spacing of traffic to get them in and out of the runways. Control messages due to other traffic (e.g., overflights) constitute the rest. Therefore, in addition to subsystems required for automatic message generation and delivery, other required detailed features are:

- Interleaving of departures and arrivals using either the same runway or dependent runways.
- Precise delivery of departures to the en route system at requested points and times.
- Automated interfaces with the Wake Vortex Avoidance Systems, and the Airport Surface Traffic Control System.
- Automated flight data and control data distribution capabilities in order to make available to the system: data on specific runways to be used by each departure, its position in the departure queue, its readiness to depart in addition to aircraft type and departure fix data already available in the system.

The combined productivity gain impact of Advanced Automation on large ARTS-III facilities (including both the IFR room and tower CAB) is shown in this report to be about 1.33. The impact on medium ARTS-III facilities is also shown to be about 1.25. No impact on small facilities is expected.

Averaging the controller productivity gain over all ARTS-III facilities regardless of size results in a weighted average gain of 1.3 due to Advanced Automation. Combining this with the average gain in ARTS-III facilities expected in the pre-data link era results in a gain of 1.72. This is shown in Figure 1. The average productivity impact of non-ARTS-III facilities was evaluated to be 1.05 at the end of the pre-data link era (see Part I of this report); and, as shown in Figure 1, no impact on those facilities is expected due to automation in the data link era. An underlying assumption in the attainment of the full productivity benefits in the data link era was that they accrue linearly between 1984 and 1990. This was based on the implementation schedule (shown in Figure 2) and on assuming that the full benefits are realized two years after the implementation of Advanced Automation at the last site.

ADVANCED AUTOMATION IN EN ROUTE FACILITIES

In the data link era, the following features of Advanced Automation are expected to have an impact on controller productivity.

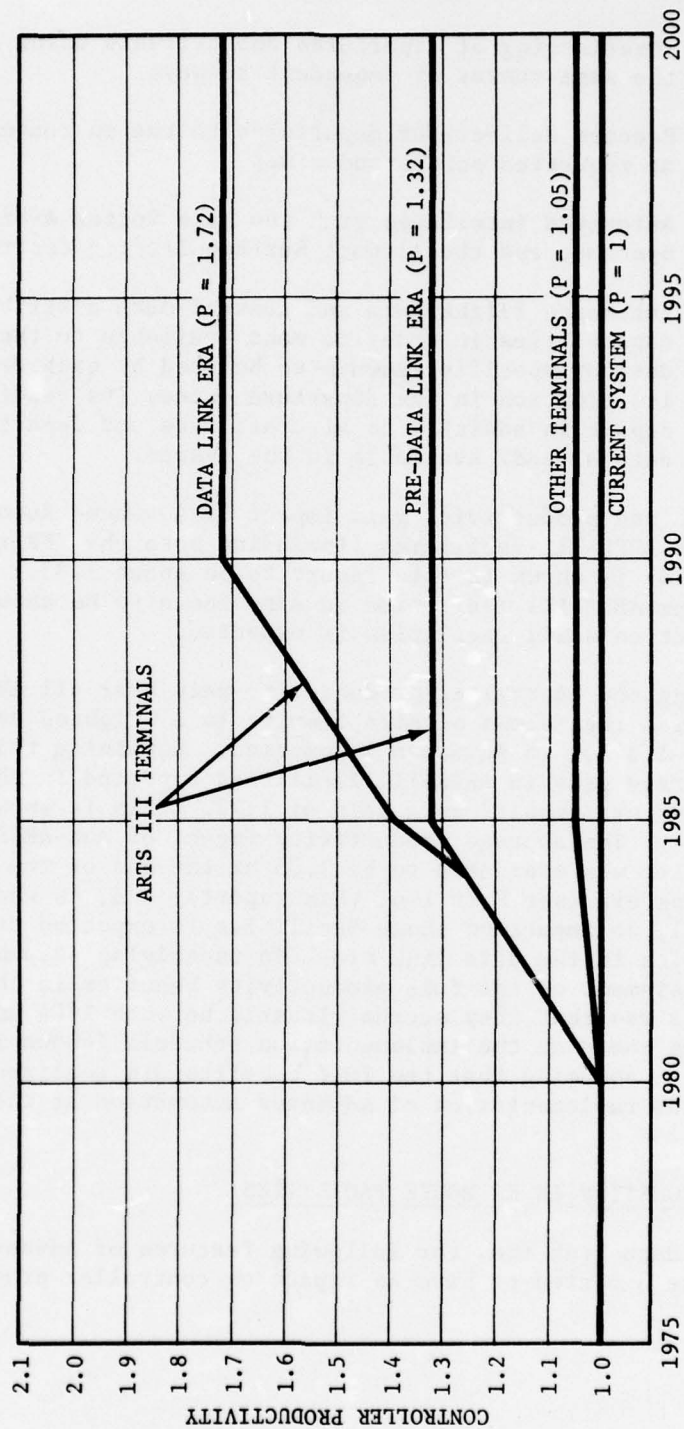
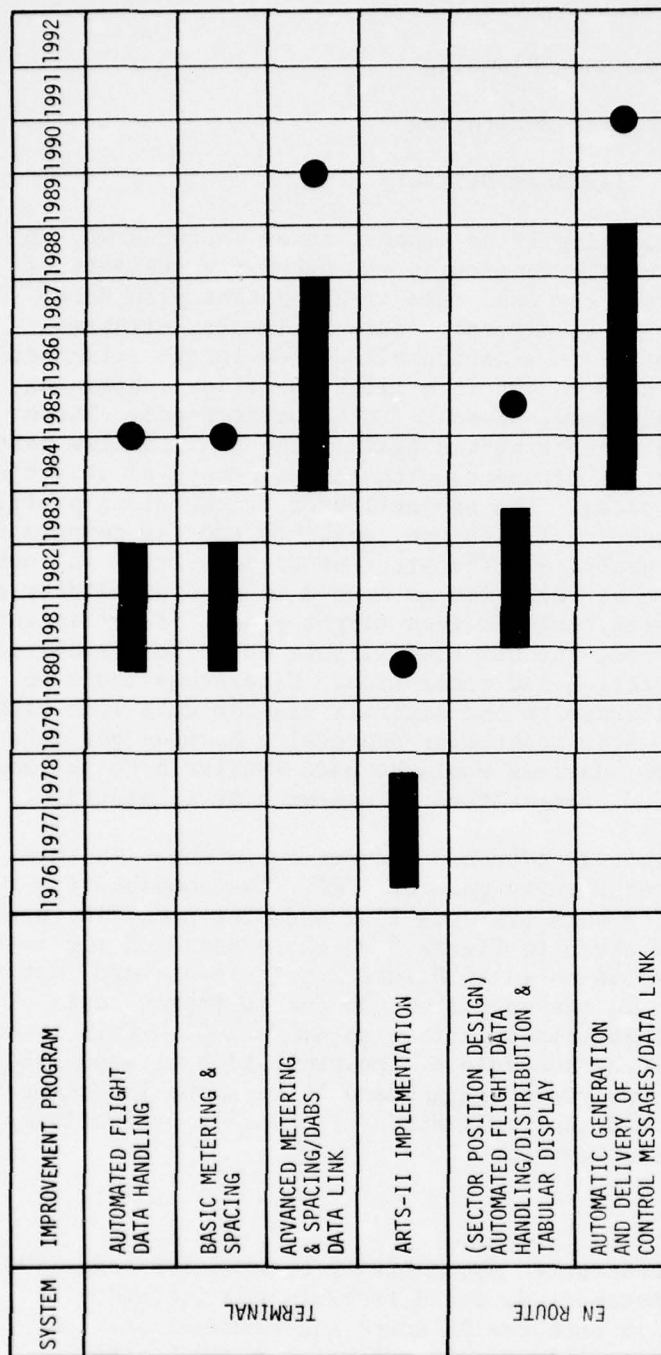


FIGURE 1
AVERAGE "WEIGHTED" CONTROLLER PRODUCTIVITY IN TERMINAL SYSTEM



● FULL BENEFITS REALIZABLE



FIGURE 2
ESTIMATED SCHEDULE OF UG3RD IMPROVEMENT PROGRAMS THAT IMPACT PRODUCTIVITY

- Flight Profile Generation
- Sector Clearance Planning
- Flight Progress Monitoring
- Automatic Clearance Delivery

Stated in an overly simplified manner, these features may be viewed as the automatic generation and automatic delivery of control messages via the DABS data link. Flight plan data, current ATC clearances, aircraft characteristics, airspace structure and weather information all stored in the automated system, would be used to generate flight profiles containing accurate route, altitude, speed and time projections. These projections would then be tested against the traffic flow pattern within the facility's airspace, with the objective of selecting a minimum time profile. The projection of tracks along profiles would allow the testing for future conflicts and the computation of conflict free profiles. The progress of each track in route and altitude would be rechecked as needed to assure validity of stored and displayed conflict free flight plan. If sufficient deviation were found, the affected flights would be resubmitted for conflict prediction and resolution. Clearances could be generated and delivered to the aircraft via the data link either automatically or after controller approval. Display and data entry and retrieval devices would be made available to the controller for maximum facilitation of man-machine interaction.

The potential impact of Advanced Automation is shown in this report to be a productivity gain of 1.62. The combined productivity impact of both pre-data link and post-data link eras is 2.19. This is shown in Figure 3 which is based on the implementation schedule shown in Figure 2. It is assumed that the productivity gain in the data link era due to improvements of that period increases linearly from unity to 1.62. This is consistent with a linear schedule of implementation between 1984 and 1989. Also, two years are assumed between the implementation of the last site and the realization of the full productivity potential of the improvements.

STAFFING COSTS

The increase in controller productivity between 1985 and 1990, due to Advanced Automation, would restrain the increases in controller staff in both the En Route and Terminal systems. Substantial savings would result. Figures 4 and 5 show the

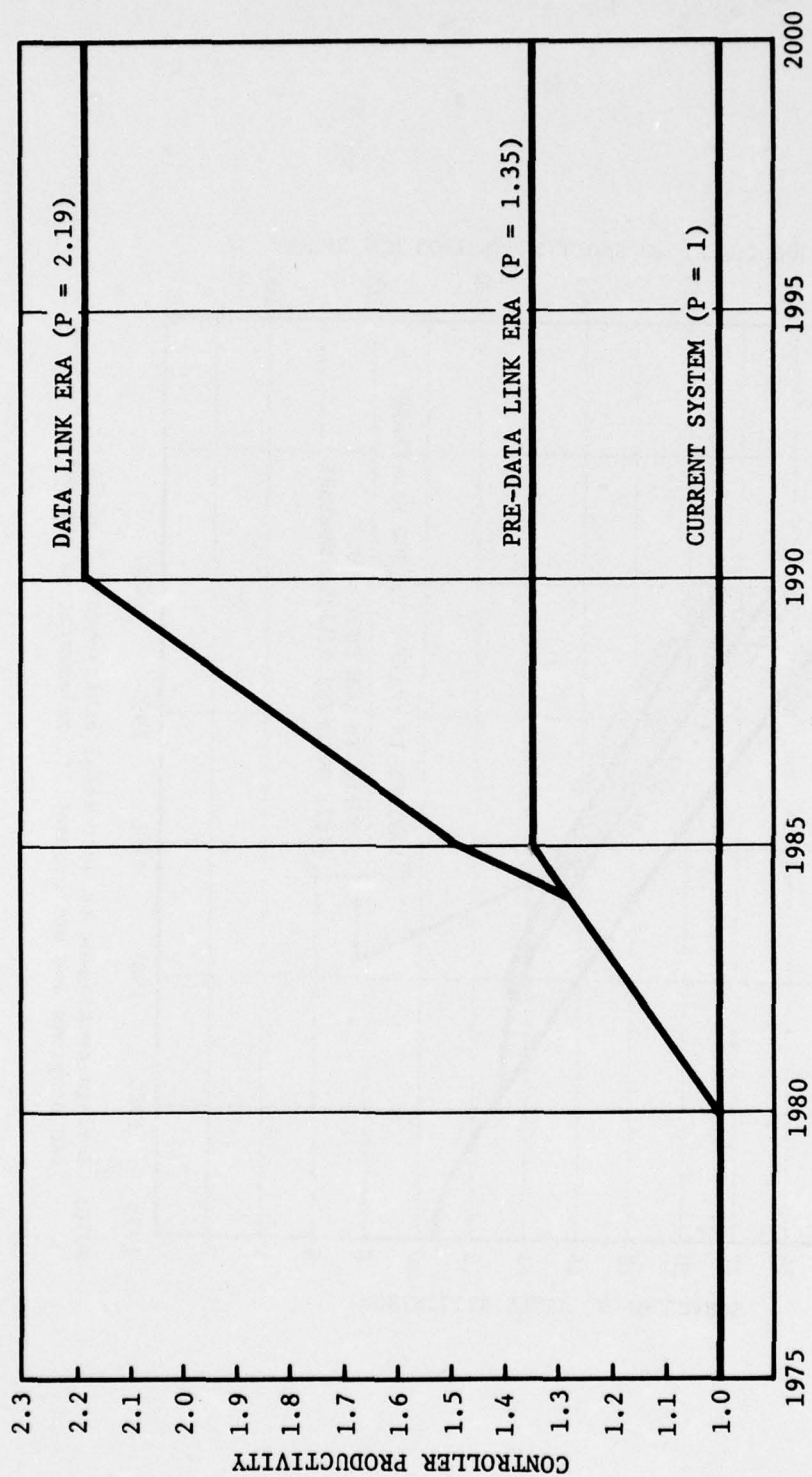
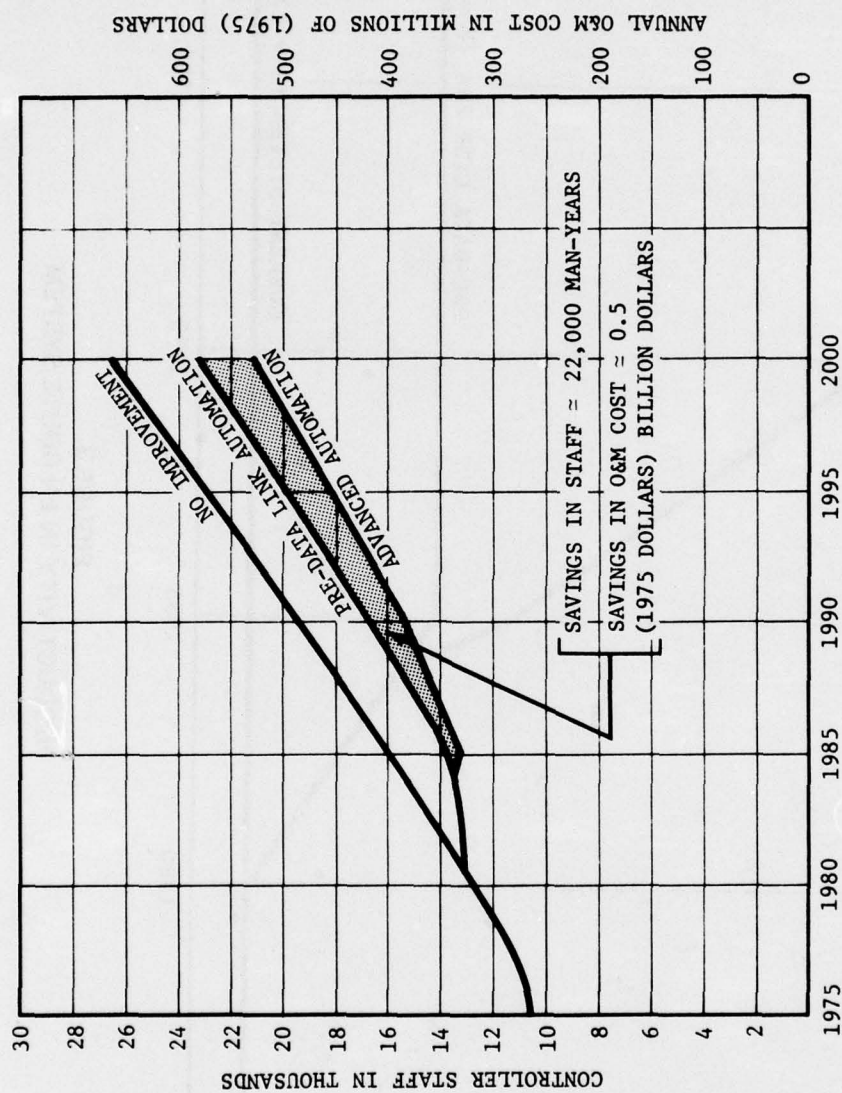
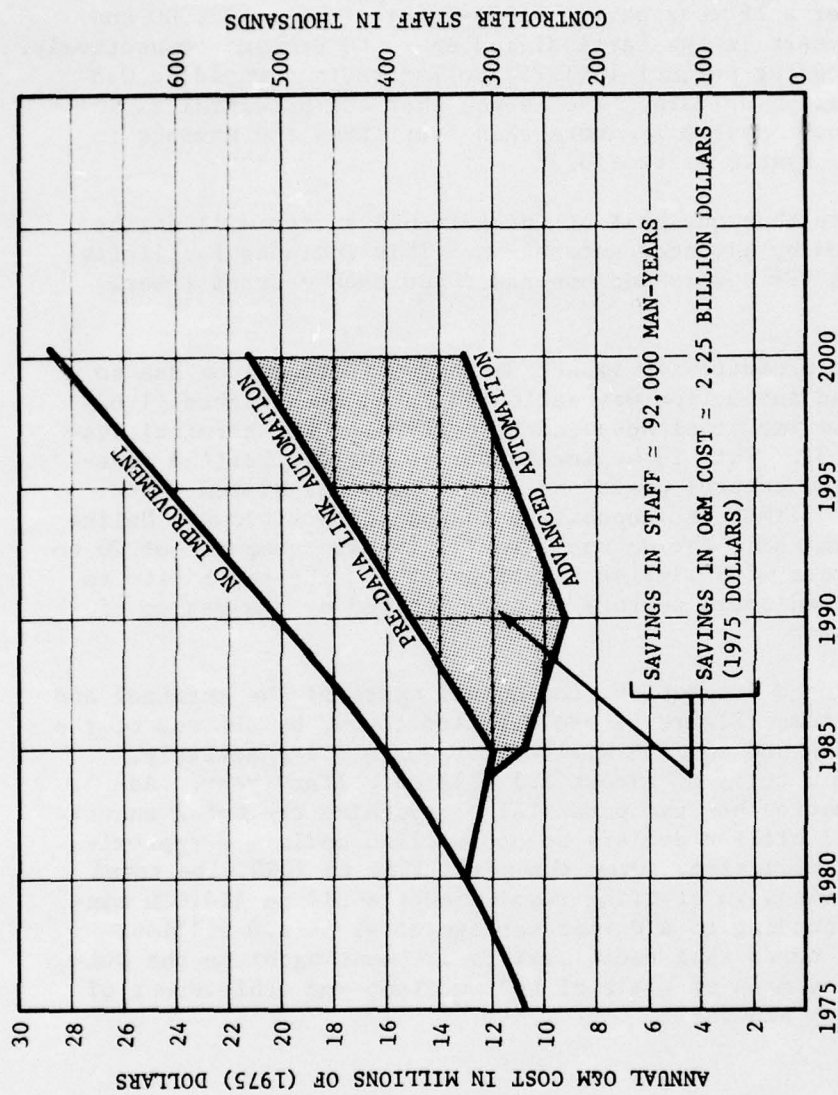


FIGURE 3
PRODUCTIVITY IN EN ROUTE SYSTEM



NOTE: Savings contingent on successful achievement of goals of E&D programs and achievement of implementation schedules.

FIGURE 4
POTENTIAL SAVINGS IN TERMINAL SYSTEM O&M
COST DUE TO UG3RD IMPROVEMENTS



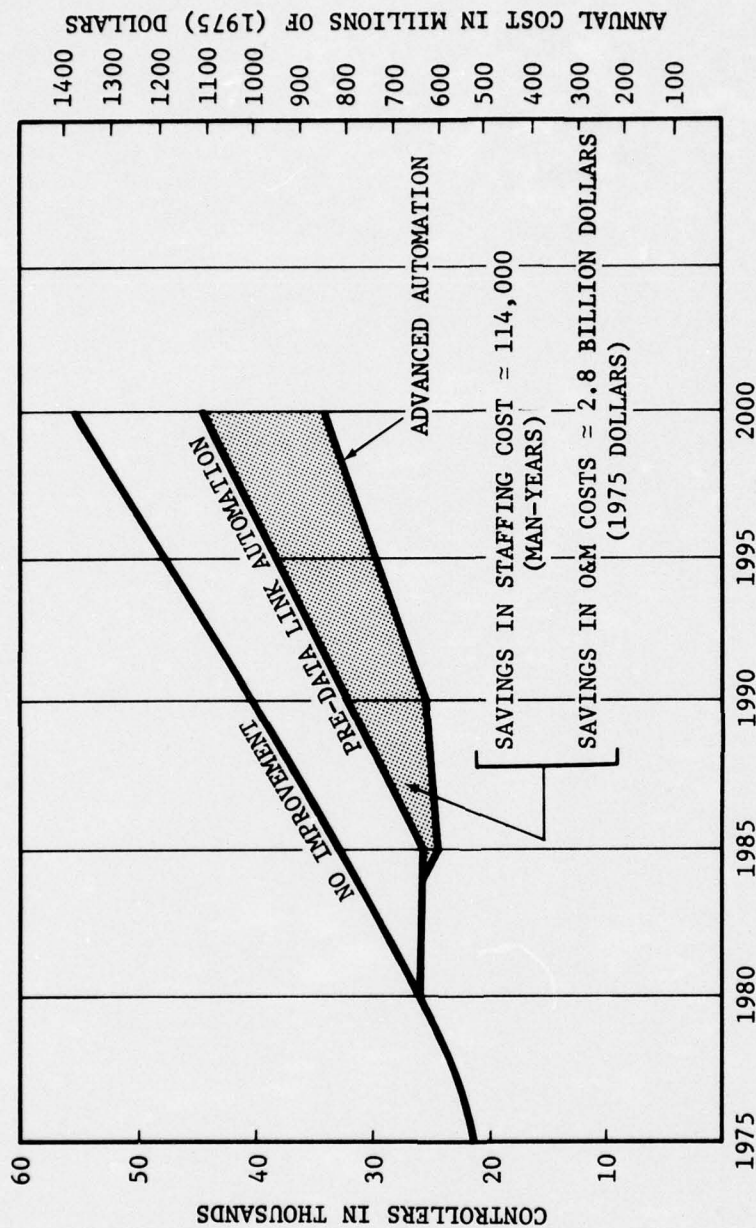
NOTE: Savings contingent on successful achievement of goals of E&D programs and achievement of implementation schedules.

FIGURE 5
POTENTIAL SAVINGS IN EN ROUTE SYSTEM O&M COST
DUE TO UG3RD IMPROVEMENTS

potential savings in the terminal and en route facilities due to UG3RD Automation improvements, both for the data link as well as the pre-data link eras. The figures show that the potential savings in staffing due to the advanced automation in the data link era over a 16 year period (1984-2000) could be 22,000 and 92,000 man-years in the terminal and en route systems respectively. The corresponding potential (1975) dollar savings would be 0.5 and 2.25 billion dollars. The reason that the potential savings in the en route system are more than four times the savings in the terminal system is two-fold:

1. More than one-half of the terminal system will not be affected by Advanced Automation. This includes facilities such as VFR towers and non-radar approach control towers, etc.
2. The productivity impact on the en route system due to Advanced Automation was estimated to be much higher (1.62) than the impact of Advanced Automation on the terminal system (1.3). This is basically due to the diversified functions and control positions in the terminal system which tends to limit the capability to combine positions. Unlike the terminals, the en route facilities are composed of 20 to 40 sectors with similar functions, thus, the capability to combine en route sectors is only limited by the degree of automation.

Without Advanced Automation, the annual costs of the terminal and en route systems (Figure 6) are expected to be, by the end of the century, about 580 and 530 millions of dollars respectively, adding up to a total of almost 1.1 billion dollars/year. Advanced Automation has the potential of reducing the total annual cost from 1.1 billion dollars to 840 million dollars - approximately a 25% reduction. Over the years 1984 to 2000, the total potential savings in staffing requirements would be 114,000 man-years corresponding to a dollar savings of about 2.8 billion. It should be noted that these savings are contingent on the successful achievement of goals of E&D programs and achievement of implementation schedules.



NOTE: Savings contingent on successful achievement of goals of E&D programs and achievement of implementation schedules.

FIGURE 6
TOTAL POTENTIAL SAVINGS IN EN ROUTE AND TERMINAL SYSTEMS
O&M COSTS DUE TO UG3RD IMPROVEMENTS

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1. INTRODUCTION

1.1 Background

According to the latest Federal Aviation Administration (FAA) forecasts, (1, 2) aircraft operations at controlled airports and Instrument Flight Rule (IFR) handles are expected to double in the period between 1985 and the year 2000. If they do, and if the Air Traffic Control facility ratios of flights served to controller staffs needed were not significantly increased beyond what is expected in the pre-data link era, staff sizes would rise from 25,000 to 45,000 controllers (unconstrained growth) in both the en route and terminal systems assuming pre-data link automation only. The annual O&M cost would increase from 670 million dollars to 1.1 billion dollars, assuming constant 1975 dollars and the present rate of \$24,600 per man-year. This excessive cost increase can be reduced by increasing the productivity of the air traffic controllers.

In 1971, the FAA published its first report ⁽³⁾ on the increase in controller productivity which might be expected as a result of the Upgraded Third (UG3RD) Generation ATC system improvement program. In the fall of 1974, the Department of Transportation in its staff study ⁽⁴⁾ of the UG3RD asked the FAA to reassess the expected benefits of the UG3RD including its impact on controller productivity. The MITRE Corporation was then tasked by the FAA Office of Systems Engineering Management (OSEM) with updating that study. The study results and the work performed are documented in a two part report. Part I ⁽⁵⁾ dealt with the time frame prior to the implementation of the Discrete Address Beacon System (DABS) and its associated data link (from the mid-70's to the mid-80's). This document (Part II) deals with advances in automation, which are now in the conceptual stages; but are planned for operational implementation in the mid-1980's.

1.2 Scope

The basic guidelines established by the FAA's Office of Systems Engineering Management for this study/update were as follows:

- Review all the pertinent literature published to date on controller productivity.

- Review those parts of the UG3RD development program aimed at improving controller productivity and make an assessment as to the increased productivity which appears to be realizable.
- Calculate future en route and terminal area ATC facility staffing and O&M costs, both with and without the implementation of the UG3RD productivity improvement programs.

1.3 Literature Review

The following is a listing of the publications that were reviewed and of the organizations that issued them. The literature was used in this report whenever applicable, and the studies were referenced as appropriate.

STANFORD RESEARCH INSTITUTE (SRI)

- "Capacity and Productivity Implications of En Route ATC Automation," by G. J. Couluris, et al., FAA Report Number FAA-RD-74-196, dated December 1974.
- "Case Study of the UG3RD Generation En Route ATC System Staffing Estimates for the Los Angeles Center," by G. J. Couluris. A draft report number FAA-AVP-75-5, dated June 1975.
- "An Evaluation and Design Criteria for ATC En Route Sector Configurations," FAA-RD-74-216 by Schmidt, et al., dated December 1974.
- "The Air Traffic Controller's Contribution to ATC System Capacity in Manual and Automated Environments Vol. II and Vol. III," by Ratner, et al., FAA-RD-72-63, dated June 1972.

THE METIS CORPORATION

- "ARTS-III Enhancements Costs and Benefits," a draft report number FAA-AVP-75-3, prepared by The METIS Corporation, dated August 1975.

AIR TRAFFIC SERVICE/OFFICE OF MANAGEMENT SYSTEMS (AAT/AMS)

- "A Staffing Standard Study of ARTS-III Facilities," an FAA Study conducted by Air Traffic Service and Office of Management System, dated April 1975.

TRW

- "Automation Applications in an Advanced Air Traffic Management System," report number DOT-TSC-OST-74-14, dated August 1974.

NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER (NAFEC)

- "Preliminary Two-Dimensional Area Navigation Terminal Simulation," an FAA report number FAA-RD-74-209, dated 23 July 1975.

1.4 Organization of the Report

The results of this study of controller productivity is being published in two parts. This document, Part II, deals with the impact of the UG3RD programs which will be achieved when the data link is available as a result of implementing the Discrete Address Beacon System program and when advanced automation has been developed for the automatic generation of ATC messages. Part I dealt with the impact of the UG3RD improvements to be implemented in the near term (1976-1985).

This document is organized as follows: In Section 2, expected future trends in air traffic activity and corresponding staffing requirements are examined with and without the increase in controller productivity expected to be achieved in the pre-data link era. Section 3 is a discussion of controller productivity and its relationship to workload reduction. In Section 4, the advanced automation programs in the terminal facilities and estimates of their potential productivity impact are developed. Section 5 presents a similar analysis for the en route facilities. The last section (Section 6), converts the productivity assessments of Sections 4 and 5 into calculations of the associated staffing requirements and presents a comparison between those requirements and the staffing requirements which would be needed if there was no increase in productivity.

2. TRENDS IN TRAFFIC AND STAFFING REQUIREMENTS

In this section the future trends in traffic and the associated growth in staffing requirements for both the en route and terminal facilities will be discussed assuming no increase in controller productivity due to advanced automation.

2.1 Trends in the Terminal System

According to the latest FAA Forecasts^(1, 2), the traffic growth in the terminal system is expected to approximately double between 1985 and the year 2000. Accordingly, the staffing requirements would have to grow substantially in order to handle this traffic increase. Figure 2-1 shows the expected future trends in aircraft and instrument operations from 1975 to the year 2000. Figure 2-2 shows the corresponding expected trends in staffing requirements for the whole terminal system and for the ARTS-III terminals. The latter chart shows the trend in the baseline system (assuming no automation) as calculated by the FAA staffing equations and by the staffing model developed in Part I of this report. The chart also shows the expected growth in staffing assuming productivity benefits realizable from the implementation of the pre-data link improvements. Although those improvements reduce the staffing requirements from those of the baseline system, the staffing of the ARTS-III terminals is still expected to grow from approximately 5,000 controllers to 9,000 controllers. This represents a growth in the ARTS-III terminal staff of about 80%. Restricting this growth is the objective of Advanced Automation concepts for the terminal facilities in the data link era and is the subject of the terminal automation section in this report.

2.2 Trends in the En Route System

It is also expected that the growth^(1, 2) in en route traffic (Figure 2-3) would nearly double between 1985 and the end of the century. The controller staff required to operate this system would have to increase accordingly. Figure 2-4 shows that the staffing requirements of the baseline system (without any automation) would grow from 16,000 in 1985 to 29,000 controllers by the year 2000. This represents a growth of about 80%. With the automation planned for the pre-data link era, the controller staff requirement would be reduced, but would

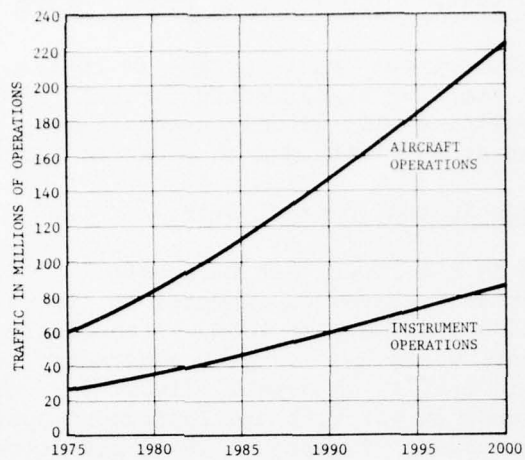


FIGURE 2-1
FORECAST IN TERMINAL OPERATIONS

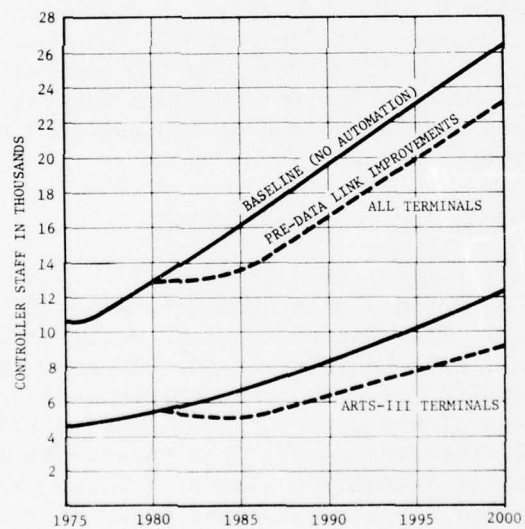


FIGURE 2-2
FORECAST IN TERMINAL STAFFING ASSUMING NO PRODUCTIVITY
INCREASES DUE TO ADVANCED AUTOMATION

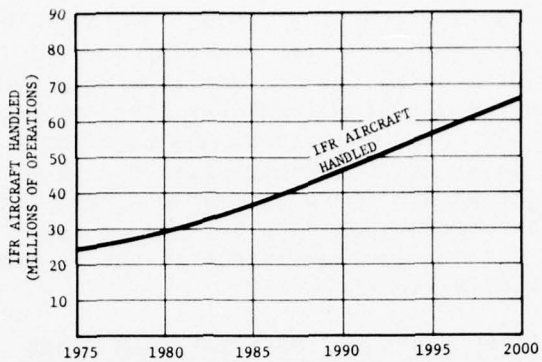


FIGURE 2.3
FORECAST IN EN ROUTE OPERATIONS

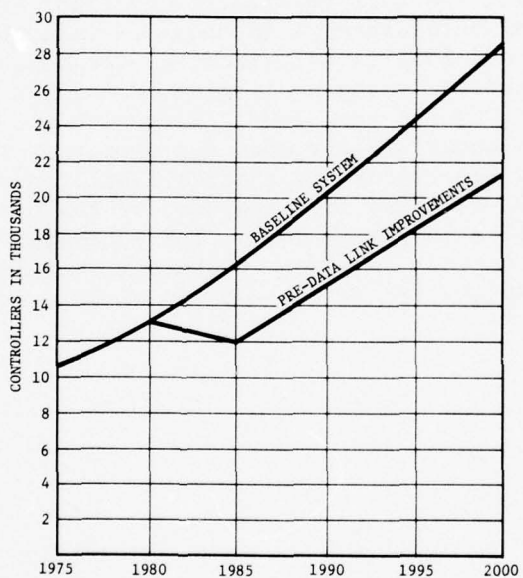


FIGURE 2.4
FORECAST IN EN ROUTE STAFF ASSUMING NO PRODUCTIVITY
INCREASE DUE TO ADVANCED AUTOMATION

still grow during the same period from 12,000 to 21,000 controllers or about 75%. The staffing for the baseline system was calculated using the FAA staffing equation, while staffing for the improved system (pre-data link) system was calculated by the use of the productivity and staffing model developed in Part I of this report. Restricting the growth of the staffing requirements in the en route system is the objective of the advanced automation concepts for the en route system in the data link era and is the subject of the En Route Automation section of this report.

2.3 Total (En Route and Terminal) O&M Costs

The trend in total staffing costs for air traffic control in the en route and terminal systems is shown in Figure 2-5 for both the baseline as well as the improved systems assuming pre-data link improvements only. Growth in the baseline system means increasing the controller staff from 32,500 by 1985 to 55,000 by the year 2000. By then, the cost of ATC is about 1,350 million dollars per year in terms of 1975 dollars. Assuming the improvements planned for the pre-data link era are implemented and assuming the full realization of their productivity impact, the growth would decrease in absolute value but the rate of growth beyond 1985 is not significantly impacted. Thus, staffing in the improved system would grow from 25,000 by 1985 to 45,000 controllers by the year 2000. Even with pre-data link improvements, the annual dollar cost for operating the ATC system at the end of the century is about 1.1 billion dollars. This is about a 20% decrease from the cost of the baseline system, but it is still a very high cost. The potential of reducing this cost by a further increase in controller productivity due to Advanced Automation is the subject of this report.

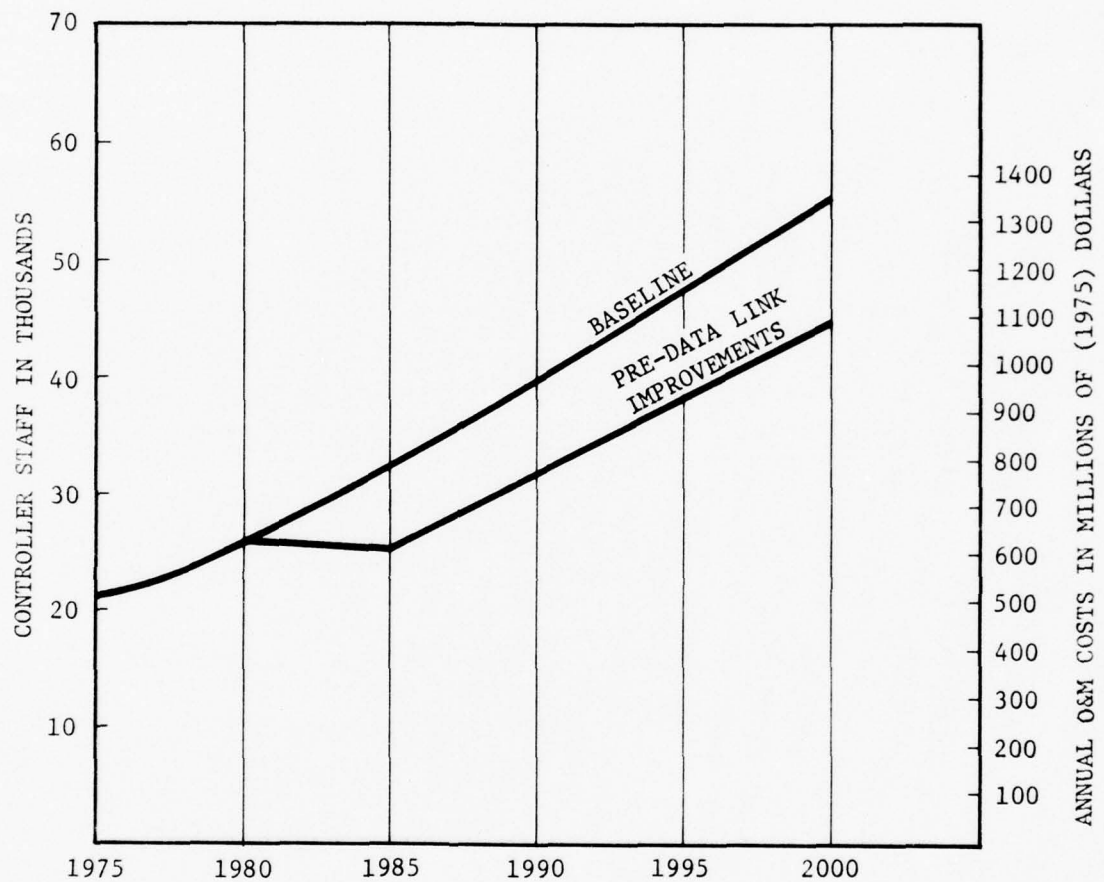


FIGURE 2-5
GROWTH IN STAFFING AND O&M COST IN EN ROUTE AND
TERMINAL SYSTEMS WITHOUT AN INCREASE IN CONTROLLER
PRODUCTIVITY DUE TO ADVANCED AUTOMATION

3. CONTROLLER PRODUCTIVITY

In the context of this study, the controller productivity measure to be used has to meet one essential constraint: it should be possible by means of this measure to assess the individual impact of an automation program on the staffing requirements in both the en route and the terminal systems. This constraint added to the fact that the staffing standard is essentially based on the peak hourly traffic in the three daily shifts, suggests the use of a controller productivity measure defined over a period of an hour. The following definition was therefore used in this report:

Definition - The productivity of the air traffic controller is defined to mean the demand serviced per controller, per hour. The demand serviced can be viewed as the number of aircraft handled per controller.

This is a widely accepted definition in the ATC community. It is, however, important to note the difficulties associated with the productivity concept as a measure of system performance. Any measurement of a control system performance that involves humans directly in the control loop is "elastic." This means that it is difficult to measure the limits on the human's capacity because those limits vary. Thus, the performance of an air traffic controller may vary from day to day, even from hour to hour, depending on many factors that could go under the umbrella of the "psychological conditions." Similarly, the performance of one air traffic controller may be different from that of another controller for the same reasons even though both of them control the same airspace (at different times). This human "elasticity" contributes to a high degree of uncertainty in any measures entertained for the purpose of calibrating productivity or other system parameters. It is, therefore, plausible and quite adequate to use judgement in estimating productivity gains or reductions. That judgement, however, should be based on averages and aggregates rather than on one controller's performance under a variety of conditions.

3.1 Definition of Controller Productivity Gain

In order to quantify the effects of changes in the automated system on controller staffing, the concept of "productivity gain" has been defined⁽³⁾ as the following ratio:

$$P = \frac{\text{Demand Serviced Per Controller in an Improved System}}{\text{Demand Serviced Per Controller in the Present System}} \quad (3-1)$$

or

$$P = \frac{\text{Controller Productivity in an Improved System}}{\text{Controller Productivity in the Present System}} \quad (3-2)$$

For example, $P = 2$ implies either:

1. Twice the demand can be serviced with the same number of controllers,
2. The same demand can be serviced by half the number of controllers.

In this study, it was assumed that the controller is working on the average at the same "pace" or "strain" level in either system.

3.2 Productivity and Workload Reduction

The workload associated with the serviced demand would be reduced with the aid of automation. This reduction in workload may or may not result in a productivity gain. In general, the relationship between controller productivity and workload is not a straightforward one. There are cases where reduction in workload could not result in the elimination of control positions, or even combining them. For example, the local controller position would always be required in towers regardless of the activity. However, there are cases where it is reasonable to expect that reduction in workload could eliminate the need for a control position or could make it possible to perform its residual unautomated functions from another control position. The combined performance of two functions by one control position is not unusual in the terminal system today. For example, the ground control function and the clearance delivery function are combined at some lower activity towers. In certain TRACABS, the local controllers also perform the approach control function in addition to their regular duties. This function is generally performed from the IFR room in other TRACON configurations. In the IFR rooms (or in the en route system) it may be possible, under certain reduced workload conditions to resectorize and combine the airspace so that fewer controllers control the same airspace.

In view of the foregoing discussion, the following statements can therefore be made:

For constant traffic, reducing workload could lead to a reduction in number of controllers and, therefore, increased productivity if:

- positions can be eliminated (e.g., flight data)
- airspace can be reorganized so controllers can handle more traffic (e.g., approach and departure in terminal systems, or radar controller in the En Route System).

Alternatively, for a higher traffic environment (such as in 1985), today's controllers could possibly handle more traffic with increased automation. The productivity due to increased automation will be discussed in this report assuming today's traffic levels.

In applying the controller productivity gain definition to both the en route and terminal systems, controller work assignments will be examined for an assessment of how those assignments will be impacted by the UG3RD automation programs. It should be noted that the derived productivities are thus dependent on the starting point (i.e., the current view of controller assignments). Ultimately, however, this is an FAA management problem which may be resolved differently by using alternate restructuring of the assignments and procedures.

4. ADVANCED AUTOMATION IN TERMINAL FACILITIES

4.1 General

In Part I of this report, the following Terminal Automation Programs planned for implementation in the pre-data link era were addressed for their impact on controller productivity:

- Automated Flight Data Handling/Distribution
- Metering and Spacing
- Conflict Alert
- Radar Tracking
- Minimum Safe Altitude Warning
- Area Navigation
- En Route Metering

Of these programs, it was found that Automated Flight Data Handling/Distribution and Metering and Spacing could have the most significant impact on controller productivity. The combined productivity impact due to these two improvements on ARTS-III terminals and non ARTS-III terminals was found to be 1.32 and 1.05 respectively. For a detailed discussion of these and the other improvement programs of the pre-data link era, the reader is referred to Part I of this report. Here in Part II, the discussion will focus on the Advanced Automation programs which are currently being considered as a part of the data link era of the UG3RD. These programs have three main features:

- Automatic Generation of Routine Control Messages
- Automatic Delivery of Control Messages via Data Link
- Advanced Metering and Spacing (Multiple Runway and Departure)

The above three features are strongly related especially since in the terminal area, control messages related to Metering and Spacing constitute a significant subset of all control messages and the controller has to handle.

The actual sequence of the different phases of the Metering and Spacing program is not of great importance from the productivity standpoint since the main impact on controller productivity is due to automating the generation and delivery of the control messages and not due to Advanced Metering and Spacing (AMS) itself. The detailed features⁽⁶⁾ of Metering and Spacing assumed in this report are:

- Interleaving of departures and arrivals using either the same runway or dependent runways.
- Precise delivery of departures to the en route system at requested points and times.
- Dynamic and adaptive variation of separation minima depending on the aircraft pairings and aircraft characteristics.
- Automated interfaces with the Wake Vortex Avoidance System, and the Airport Surface Traffic Control System.
- Automated flight data and control data distribution capabilities in order to make available to the system: data on specific runways to be used by each departure, its position in the departure queue, its readiness to depart in addition to aircraft type and departure fix data already available in the system.

The introduction of the Advanced Automation will have a substantial impact on communications and coordination workload. In analyzing the effect of this impact on productivity in the different terminal types, the operations of these terminals will be discussed in terms of today's traffic, and assuming that the productivity oriented automation improvements of the pre-data link era are already implemented and fully operational. The degree to which the advanced automation features would be implemented in terminals is a function of the facility size and traffic volume.

4.2 Staffing of an Average Facility

The staffing of an average terminal facility whether or not it is an ARTS-III facility was derived from a staffing model developed in detail in Part I of this report. In this section, this model will be described only briefly; and the reader is referred to Part I for additional detail.

The approach consisted simply of relating the traffic activity to the terminal staff, not only by considering the aggregate traffic activity and staff in the terminal system as a whole, but also by considering the average staff requirements and the average air traffic activity of different types of terminal facilities. To this end, data was obtained from Air Traffic Service (AAT-130), which provided a listing of all the FAA Terminal facilities by name, type and regional jurisdiction as well as the 1974 staffing and air traffic activity for each terminal facility (see Table 4-1). The data was then analyzed to obtain a relationship between the required staff and the traffic activity as measured by Aircraft Operations (AO) and Instrument Operations (IO). This relationship was then used to determine the staffing of an average facility. To compute the average AO's and IO's per facility for any future year, the 1974 distribution of traffic among the terminal types was assumed to hold except for a minor adjustment to allow for the upgrading of facilities as assumed by the Ten Year Plan.⁽⁷⁾ The average staff per terminal facility of a certain type was then multiplied by the number of facilities of that type. The total terminal system staff was then found by summing over all types of facilities.

In order to derive controller productivity estimates, it was necessary to examine the peak shift staffing for the possible elimination of control positions or increase in the controlled traffic per controller. The peak shift staffing was derived from the average annual facility staff as follows: First, the Supervisory and the Data System Specialist staff was subtracted from the average annual staff in accordance with the rules outlined in the staffing standard. Second, the remainder was divided by 1.6, which is a factor that accounts for a five day week and administrative leaves, etc. The results is the daily staffing requirement. The three daily shifts, DAY, EVE, and MID shifts, were assumed to require 45%, 45% and 10% of the terminal's daily staffing requirements respectively. A control team structure during the peak shift was assumed for all average facilities based on airport surveys⁽⁸⁾ by NAFEC and actual observations of different facility types.

Automation programs of the pre-data link era were then analyzed for their impact on the team structure and adjustments were made which would result in the productivity impact. The structures of the control teams at the advent of the data link era (after the pre-data link improvements were implemented and their productivity fully reaped) were derived in Part I of this report and the results are shown in Table 4-2 and Table 4-3 for the ARTS-III and smaller facilities respectively.

TABLE 4-1
TYPES OF TERMINAL FACILITIES

FROM STAFFING STANDARD		NAME	FACILITY MAKEUP	ARTS PARTICIPATION
TYPE				
5		RADAR APPROACH CONTROL TERMINAL	IFR ROOM AND CAB	LARGE AND MEDIUM - ARTS-III SOME SMALL - ARTS-II*
9		RADAR APPROACH CONTROL FACILITY (e.g., NEW YORK IFRR)	IFR ROOM/ NO CAB	LARGE - ARTS-III MOST SMALL - ARTS-II*
7		LIMITED RADAR APPROACH CONTROL TOWER (e.g., JFK)	CAB ONLY	ASSOCIATED WITH ARTS-III FACILITIES
8		RADAR APPROACH CONTROL TOWER	TRACAB	SOME ARTS-II*
3,4		NON RADAR APPROACH CONTROL TOWER	CAB ONLY	NONE
1,2		VFR TOWER	CAB ONLY	NONE

* TO BE IMPLEMENTED.

TABLE 4-2
PEAK SHIFT STAFFING OF AVERAGE ARTS-III FACILITIES
AT THE ADVENT OF THE DATA LINK ERA

LOCATION	CONTROLLERS	TRACON & CAB		LARGE TRACON/ NO CAB	LIMITED RADAR APPROACH CONTROL TOWERS
		LARGE	MEDIUM		
IFR ROOM	FINAL APPROACH	4	1	4	
	ARRIVAL		3		
	DEPARTURE	3	2	3	
	COORDINATOR/HANDOFF	0	0	0	
	FLIGHT DATA	1	1	1	
	TOTAL IFR ROOM	8	7	8	
	LOCAL	1	1		1
TOWER CAB	ASSISTANT LOCAL	0	-		0
	GROUND	1	1		1
	CLEARANCE DELIVERY	1	1		1
	FLIGHT DATA	1			1
	TOTAL TOWER CAB	4	3		4
	TOTAL CONTROLLERS	12	10	8	4

TABLE 4-3
STRUCTURE OF CONTROL TEAM IN AVERAGE SMALL FACILITIES

LOCATION	CONTROLLERS	TRACON & CAB	TRACON/ NO CAB	TRACAB	NON RADAR APPROACH CONTROL TOWERS	VFR TOWERS
IFR ROOM	ARRIVAL	1	2			
	DEPARTURE	1	2			
	COORDINATOR/HANDOFF	0	0			
	FLIGHT DATA	1	1			
	TOTAL IFR ROOM	3	5			
TOWER CAB	LOCAL	1		1AC + 1LC	1AC/LC	1
	GROUND	1		1	1GC/CD	1GC/CD
	CLEARANCE DELIVERY	1				
	FLIGHT DATA	1			1	0.2
	TOTAL TOWER CAB	4		4	3	2.2
FACILITY	TOTAL CONTROLLERS	7	5	4	3	2.2

AC = APPROACH CONTROLLER
LC = LOCAL CONTROLLER
GC = GROUND CONTROLLER
CD = CLEARANCE DELIVERY

4.3 Data Link Assumptions

The general trend in air traffic seems to be that the General Aviation traffic is increasingly using the smaller terminals rather than the larger ones. Table 4-4 is an illustration of this tendency.⁽⁹⁾ For example, the table shows that during 1973, the General Aviation traffic at O'Hare airport accounted for 6% of the overall traffic, while it was one third of the traffic back in 1955. At the same time, General Aviation traffic at smaller facilities has increased so much that it accounts for more than 80% of the traffic in the examples shown (Grand Rapids, Daytona Beach and Youngstown). At Milwaukee airport, an ARTS-III medium size facility, the percent of all traffic that is general aviation has nearly doubled by 1973.

Because of these trends, it is expected that with the beginning of the data link era, the large majority of the traffic in the large ARTS-III facilities would be data link equipped and therefore, capable of taking advantage of the advanced automation systems which would then be made available in those facilities. The medium ARTS-III facilities are expected to have a mixed environment, in which a smaller, but nevertheless significant, portion of the traffic would be capable of taking advantage of the advanced automation systems implemented in those facilities. The smaller facilities (some of which would be at the ARTS-II level of automation) are not expected to have advanced automation programs implemented in them. With these assumptions, it is possible now to make an assessment of the potential productivity achievable in the different size terminal facilities.

4.4 Controller Productivity in Large ARTS-III Terminals

In the large ARTS-III facilities, all of the following three features are expected to be implemented: Advanced Metering and Spacing, Automatic Control Message Generation, and Automatic Delivery of the Control Messages via the Data Link. The following discussion is applicable to large ARTS-III TRACONS with or without a Tower CAB.

4.4.1 IFR Room

The improvements in the pre-data link era have resulted in the elimination of the handoff/coordinator position and in a small reduction in the number of approach controllers (see Part I of this report). Assuming those improvements, Table 4-2 shows that

TABLE 4-4
HISTORY OF GENERAL AVIATION TRAFFIC IN TERMINAL AREAS
(REFERENCE 9)

FACILITY SIZE	AIR CARRIER AIRPORTS	1955	1973
LARGE	O'HARE (ARTS-III)	33%	6%
	ATLANTA (ARTS-III)	48%	11%
MEDIUM	MILWAUKEE (ARTS-III)	38%	64%
SMALL	GRAND RAPIDS	60%	84%
	DAYTONA BEACH (ARTS-II)	52%	92%
	YOUNGSTOWN	27%	82%

a Large ARTS-III facility would require four arrival controllers, three departure controllers and one flight data controller in order to handle today's level of traffic. In the data link era, the implementation of Advanced Automation could significantly reduce voice communications between controllers and pilots. Since Advanced Automation enhancements would impact the Departure, as well as arrival controllers, it is expected that two instead of three departure controllers and three instead of four arrival controllers (however distributed), could handle a level of traffic equivalent to that of 1975. As shown in Table 4-5, the productivity gain due to Advanced Automation is, therefore, 1.33 for the IFR rooms of Large TRACONS with or without CABS.

4.4.2 Tower CAB

In the Tower CAB of a large ARTS-III facility (TRACON/with CAB and Limited Radar Approach Control Tower), the implementation of the data link and the Automation of Control Message Delivery would eliminate the need for the clearance delivery position, because of the assumption that a large number of aircraft using this large terminal would be data link equipped. The number of aircraft not equipped with data link is expected to be so small that a separate clearance delivery position cannot be justified. Clearance delivery to unequipped aircraft could be delivered by the flight data man or the shift supervisor. Table 4-5 shows that the impact of the controller productivity of eliminating the clearance delivery position is a factor of 1.33 for the Tower CAB of large TRACONS and for Limited Radar Approach Control Towers.

4.4.3 Facility Productivity Impact

The expected productivity impact due to advanced automation on large ARTS-III facilities is shown in Table 4-5 to be about 1.33. This is applicable to large TRACONS with and without a CAB and to Limited Radar Approach Control Towers.

4.5 Controller Productivity in Medium ARTS-III Terminals

The medium size facilities were also assumed here to have Advanced Metering and Spacing, Automation of Control Message Generation and Automation of Control Message Delivery implemented in them. However, the impact those features are expected to have on the medium size facilities is less than the impact in the large facilities because the medium size ones are expected to have a mixed environment of data-link-equipped and non-data-link-equipped

TABLE 4-5
IMPACT OF ADVANCED AUTOMATION ON ARTS-III FACILITIES STAFFING

LOCATION	CONTROLLERS	TRACON & CAB						TRACON/NO CAB		LIMITED RADAR APPROACH CONTROL TOWERS	
		LARGE		MEDIUM*		LARGE		PRE	POST	PRE	POST
		PRE	POST	PRE	POST	PRE	POST				
IFR ROOM	FINAL APPROACH	4	1	1	1	4	1				
	ARRIVAL		2	3	2		2				
	DEPARTURE	3	2	2	1	3	2				
	COORDINATOR/HANDOFF	0	0	0	0	0	0				
	FLIGHT DATA	1	1	1	1	1	1				
	TOTAL (IFR ROOM)	8	6	7	5	8	6				
	PRODUCTIVITY (IFR ROOM)	1	1.33	1	1.4	1	1.33				
TOWER CAB	LOCAL	1	1	1	1					1	1
	ASSISTANT LOCAL	0	0	-	-					0	0
	GROUND	1	1	1	1					1	1
	CLEARANCE DELIVERY	1	0	1	1					1	0
	FLIGHT DATA	1	1							1	1
	TOTAL (TOWER CAB)	4	3	3	3					4	3
	PRODUCTIVITY (TOWER CAB)	1	1.33	1	1					1	1.33
IFR ROOM & TOWER CAB	TOTAL CONTROLLER STAFF	12	9	10	8	8	6			4	3
	FACILITY PRODUCTIVITY	1	1.33	1	1.25	1	1.33			1	1.33

*ADVANCED M&S ADDED TO MEDIUMS
LARGE 100% DATA LINK
MEDIUM 50% DATA LINK

PRE: INCLUDES CONTRIBUTIONS DUE
TO AUTOMATED DATA HANDLING AND
M&S.

POST: INCLUDES IMPACT OF ADVANCED
AUTOMATION.

aircraft. For example, the clearance delivery position could not be eliminated from the tower CAB of medium facilities because of the relatively large volume of non-data-link-traffic. In the IFR room, there would be a substantial reduction in coordination and communications that positions could be consolidated so that three controllers instead of two controllers could handle the departure traffic. Table 4-5 shows that the productivity gain in the IFR room would be about 1.4 with no associated impact on the productivity in the tower CAB. The overall productivity gain considering the whole facility is, therefore, 1.25.

4.6 Smaller Facilities

It is not expected that the AM&S, Automation of Control Message Generation and Delivery and the Data Link Capability would be implemented in small facilities whether or not the facilities have an ARTS-II system. Therefore, the staffing in those facilities is expected to maintain the same structure it had in the pre-data link era. The staffing of average small facilities was derived in Part I of this report and is shown in Table 4-3.

4.7 Summary of Productivity Gain Due to Advanced Automation

A summary of the productivity impact of Advanced Automation on large ARTS-III facilities is shown in Table 4-6. The table shows both the productivity gain in the data link era as well as in the preceding era. The combined productivity gain of the two eras is also shown. The latter varies between 1.5 for medium facilities and 2.0 for some of the larger ones. Combining the productivity gain of the different types, results in an average "weighted" productivity of about 1.72 for the ARTS-III terminals. The average "weighted" productivity gain, \bar{p} , is defined as follows:

$$\bar{p} = S/S_p \quad (4-1)$$

where

S = system staff at a certain baseline automation level summed over all the ARTS-III terminal types

S_p = system staff at the new automation level summed over all the ARTS-III terminal types.

TABLE 4-6
SUMMARY OF PRODUCTIVITY* GAIN IN ARTS-III FACILITIES
(INCLUDING OVERHEAD)

	ARTS-III TRACONS WITH CAB		LARGE ARTS-III TRACONS/NO CAB	LIMITED RADAR RADAR APPROACH CONTROL TOWERS
	LARGE	MEDIUM		
PRE-DATA LINK ERA	1.42	1.2	1.38	1.5
DATA LINK ERA	1.33	1.25	1.33	1.33
TOTAL	1.89	1.5	1.84	2.0

*PRODUCTIVITY OF CURRENT SYSTEM = 1.0.

S_p is found by dividing the staffing requirement for each facility type at the advent of the data link era by the controller productivity gain expected for that type of facility due to the implementation of advanced automation, and then by summing over all types of facilities.

Table 4-7 shows a summary of the impact of automation improvements on smaller facilities. Since there is no improvement in the data link that affects those facilities, their productivity is the same as that in the pre-data link era. The average "weighted" productivity gain of these terminals found by applying equation 4-1 to small terminals is about 1.05. For details on controller productivity in smaller facilities in the pre-data link era, the reader is referred to Part I of this report.

TABLE 4-7
SUMMARY OF PRODUCTIVITY* GAIN IN SMALLER FACILITIES

	TRACON WITH CAB	TRACON WITH NO CAB	TRACAB	NON RADAR APPROACH CONTROL TOWER	VFR TOWER
PRE-DATA LINK ERA	1.14	1.2	1.0	1.0	1.0
DATA LINK ERA	1.0	1.0	1.0	1.0	1.0
TOTAL	1.14	1.2	1.0	1.0	1.0

*PRODUCTIVITY OF CURRENT SYSTEM = 1.0.

5. ADVANCED AUTOMATION IN EN ROUTE FACILITIES

5.1 General

In Part I of this report, the following en route automation programs for the pre-data link era were addressed for their impact on controller productivity:

- Control Sector Position Redesign/Tabular Display
- Conflict Alert
- Flight Plan Conflict Probe
- Central Flow Control
- Local Flow Control
- Area Navigation
- En Route Metering

Of these programs, the Control Sector Position Redesign/Tabular Display was found to have the most significant impact on controller productivity. The productivity impact due to this improvement program was found to be about 1.35. For a detailed discussion of this program and the other improvement programs of the pre-data link era, the reader is referred to Part I of this report. Here in Part II, the discussion will focus on Advanced Automation improvements which are currently being considered as part⁽¹⁰⁾ of the data link era of the UG3RD and potentially implementable in the 1985 to 1990 period. The FAA overview document⁽¹⁰⁾ states on page X-5: "The gradual deployment of DABS to cover all terminal hub areas and the busier en route airspace between these hubs will provide a high capacity, ground/air/ground data link between ATC facilities and properly equipped aircraft with coverage over much of the nation. Within this environment, the data link delivery of ATC clearances, assignments, and advisories for most IFR operations can be anticipated. Non-routine clearances and exceptions taken by the pilot will be handled either via voice radio or manual data entry devices. Advanced development activities are in progress in the en route and terminal programs to automate the various types of control messages to investigate operational procedures for their use."

The following paragraph by W. M. Flener⁽¹¹⁾ sets the tone for Advanced Automation in the en route system. "As we continue the implementation of an automatic air traffic control concept, we must be aware of the cost of personnel required to support the new system features and capabilities. The air traffic

controller of today will become the system manager of the future. More and more routine decisions will be handled by surveillance, communications, and computers as never before. As additional capabilities are added, the need for more people to operate the air traffic control system will become stable and ... may actually begin to decline or at least plateau out. The system is planned to move from a labor intensive to a machine intensive base."

In the rest of this section the current concepts in Advanced Automation will be discussed. This will be followed by a discussion of the role of the ATC controller in the data link era, and by an assessment of Advanced Automation on controller productivity.

5.2 A Scenario for Advanced ATC Automation

The following additions to the enhanced pre-data link system are currently under investigation for feasibility and practicality.

- Flight Profile Generation
- Sector Clearance Planning
- Flight Progress Monitoring
- Automatic Clearance Delivery

In total, these features simply mean the automatic generation and automatic delivery of routine control messages via the data link. In the following paragraphs these concepts will be defined.

5.2.1 Flight Profile Generation ⁽¹²⁾

Under this concept flight plan data, either filed or as amended, would be forwarded from facility to facility well ahead of an aircraft boundary crossing time. This information, together with the current ATC clearance and the aircraft stored performance characteristics, would be used to project flight profiles based on a programmed knowledge of the airspace structure of the flight path and pre-established procedures. These flight profiles which contain route, altitude, speed, and accurate time projections would then be tested against the ever changing traffic flow patterns within the facilities airspace. In these processes the aircraft track's position would be projected along the stored or updated flight profile allowing the sector planning routines to continually test for future conflicts

and compute revised conflict-free profiles -- through the sectors/centers that are impacted by the flight path. The end product would be a conflict-free plan from departure to arrival based on future position. The benefits of automated sector clearance planning are the reduction of short term sector planning and conflict prediction and resolution.

5.2.2 Flight Progress Monitoring (12, 13)

Flight progress monitoring would provide the link between the tracking system, the sector clearance planning program, and the ever changing traffic flow patterns within the facility's airspace for Conflict Prediction and Resolution. (13, 14) To these known factors current and projected weather information would be added. The final result would be the selection of a specific profile through each facility's area which approaches a minimum time track which is advantageous to the aircraft operator. The benefit of flight profile generation to air traffic control is the automatic performance of strategic planning which is being performed by the D-controller in the current ATC system.

5.2.3 Sector Clearance Planning (12, 13, 14)

Another major addition contemplated is a short term sector clearance planning function which works directly with the results of flight profile generation. This planning function would be performed a short time prior to the aircraft entry into a sector or a center airspace. Thus, this is a series of processes rather than a single automatic clearance delivery function. Real-time track updating would make possible dynamic revisions to the clearance to be issued and to the exact timing of the delivery of those clearances.

5.2.4 Automatic Clearance Delivery (12)

The clearance delivery and timing function would automatically generate the next clearance for each aircraft and could display it to the controller at the appropriate time. A two-way data link would be available to provide clearances either automatically or after controller approval for display and/or aural readout to the pilot/crew. Both voice and data link communications would be available between the controller and the aircraft. In this postulated ATC scenario it is mandatory that the computer be kept apprised of the controller actions, through a data communications link. This data communications

link would be in the form of data entry and display capability containing both graphic and keyboard input/output.

Digital-to-analog voice synthesizers may be provided either on the ground or in the aircraft for voice output of digitally encoded messages. Air/ground communications, either voice or data, would rely on the most convenient or most desired method of communications at any point during the flight. Having both the voice and data link options available to IFR aircraft would provide an additional level of backup and allow for empirical knowledge upon which to build more advanced ATC concepts. The role of voice communications in general would have to be continuously reexamined as Advanced Automation in general takes hold, but its use for emergency is almost a certainty. Therefore, voice contact between pilot and controller could be made a requirement at handoff in order to insure availability of the voice link in case of emergencies.

5.3 Controller's Role in the Data Link Era

The controller's role in the data link environment, was aptly described by Reference 15 as follows:

"As more and more automation is introduced into the ATC system, it is expected that the controller's role would undergo some changes. It is expected for example, that the controller would do more monitoring than at the present time. He would monitor and manage the automated system at his disposal (see Figure 5-1) through the displays and the data entry and retrieval devices made available to him. These devices would keep him apprised of:

1. the current air situation,
2. the clearance status of each inbound and actively controlled flight, and
3. the current clearance plan for all these flights through the remainder of the controlled airspace for which the controller is responsible.

The controller would exercise his responsibilities by monitoring these displays, querying the automated system

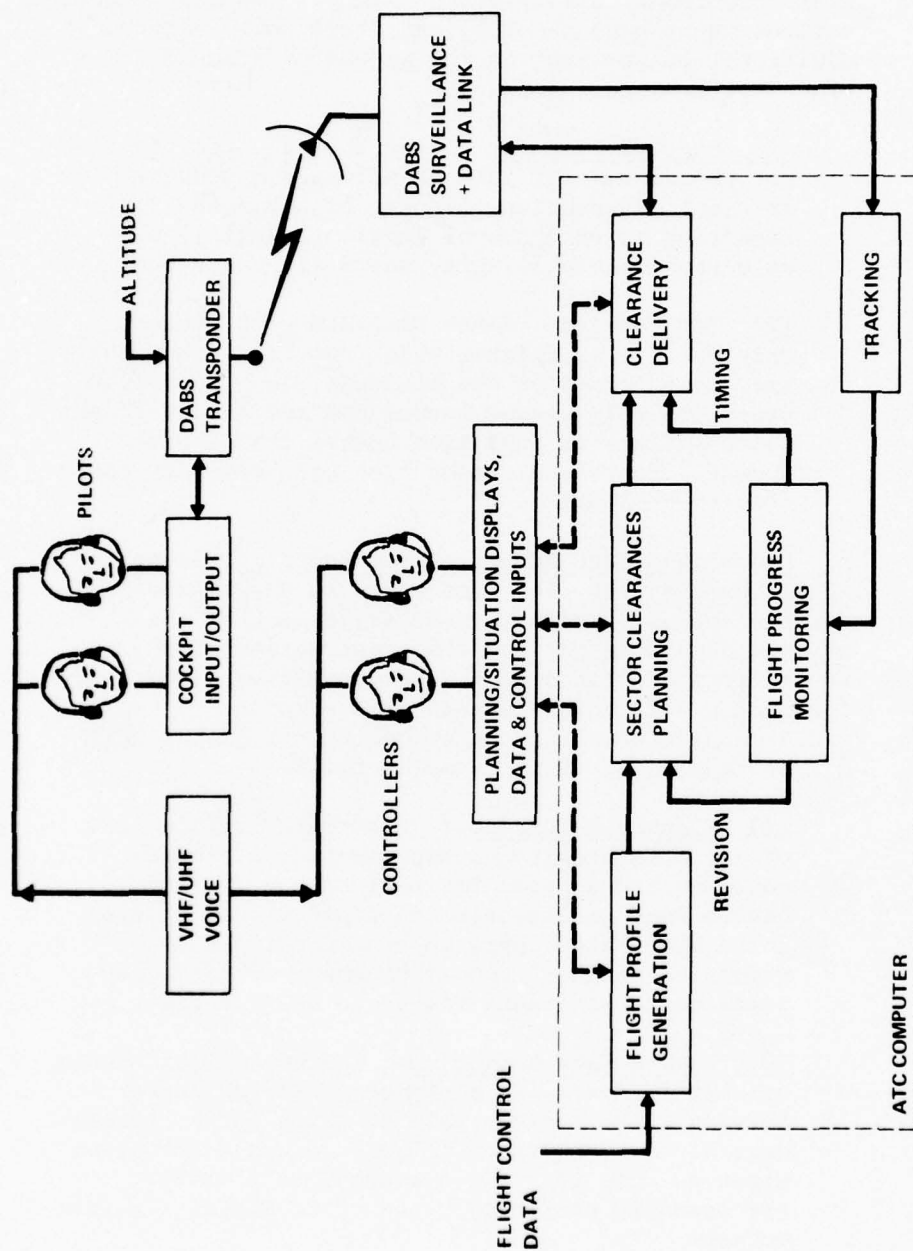


FIGURE 5-1
ELEMENTS OF AN AUTOMATED IFR TRAFFIC CONTROL SYSTEM
(REFERENCE 15)

at will, and intervening whenever he deems it necessary. Such intervention might occur in order to:

a. Manually Control Selected Flights: A particular flight might be removed for manual control from the list of automatically planned flights. Manual control actions would have priority and these would act as additional constraints on the automated planning process. Examples include:

(1) Special Flights: These include operations not programmed for such as military maneuvers or navaid inspection flights, or a flight requiring an exceptional level of service, such as a Presidential flight aboard Air Force One.

(2) Emergencies: Since the automated process only deals with flights which can be automatically tracked in position and altitude, the controller would probably assume manual control of any flight which suffers an in-flight beacon transponder outage. Procedural separation with priority could thereby be applied.

b. Manually Select New Preferred Route, Altitude or Speed Constraints: The system design should provide for the real-time selection or adjustment of the adapted data which drives the construction of the preferred route, altitude, and speed profiles. The need for such modifications arises from a variety of real world changes of which the automated system has no direct knowledge. Some examples follow:

(1) Planned Reroutings: Alternate traffic flow plans, with preplanned implementation procedures, could be pre-adapted for real-time selection to handle such foreseeable contingencies as changes in terminal area approach configurations or recurring weather frontal movements which sometimes cause alternate routes to be preferred.

(2) Random Flow Rerouting: The controller should be able to designate a random preferred route between, say, a given pair of fixes for a program-recognized category of flights. Such a rerouting might be made to avoid a weather cell blocking the normally preferred route or to bypass a navaid outage.

(3) Individual Flight Rerouting: The rerouting of a selected individual flight by other than the currently preferred routing should also be available to the controller.

Other examples could be created to illustrate controller alteration of altitude profiles by specifying new crossing altitude limits for flights inbound to a specified control point. Other control parameter adjustments might include the imposition or relaxation of flow control constraints or terminal area metering restrictions."

5.4 Productivity Impact of Advanced Automation

5.4.1 Workload Distribution Prior to Advanced Automation

Assuming that the improvements of the pre-data link era do indeed achieve their productivity potential, it was shown in Part I of this report that the workload distribution among the different functions and controllers would be as shown in Table 5-1. Basically, the table shows that the total R-man workload normalized to the 1975 traffic would be about 62% of the sector workload and that the D-controller's workload would be about 28% of the total sector's workload. The radar controller is the lead position in the sector and he handles tactically oriented functions. He is responsible for assuring the separation of aircraft, short term (tactical) traffic planning, and voice air/ground (A/G) communications using the NAS plan view display and the associated keyboard entry system. With the implementation of pre-data link improvements, the controller in the D-position would be handling "strategic" or long term functions associated with planning and sector maintenance using the Tabular Display System. He would manage and negotiate transfers of control jurisdiction responsibility for aircraft and would maintain intersector coordination. The D-controller also would have a keyboard entry set and could communicate with the NAS computer system.

The efficient use of the time of the D-controller would require reducing the workload of the R-controller to the point where the sector is capable of handling more aircraft and therefore controlling more airspace to the point where the services of the D-controller could be shared by two sectors. This could be accomplished by the improvements brought about by Advanced Automation.

TABLE 5-1
DISTRIBUTION OF EN ROUTE SECTOR WORKLOAD
(AROUND 1985)

CONTROLLER	FUNCTION	MAN-MIN. PER HOUR	PERCENT OF TOTAL
RADAR (TACTICALLY ORIENTED FUNCTIONS)	COMMUNICATIONS	22.4	35%
	CONFLICT PREDICTION/RESOLUTION	8.3	13%
	SURVEILLANCE/MONITORING	10.7	16%
	MANUAL/CONSOLE OPERATIONS	5.0	8%
D-CONTROLLER	TOTAL R-MAN	46.4	62%
	PLANNING	18	28%
	TOTAL SECTOR	64.4	100%

5.4.2 Controller Productivity in the Data Link Era

Automatically generated and delivered instructions to controlled aircraft can be expected to (a) significantly reduce voice communications workload, and to (b) translate into an increase in the traffic handling capacity of the "radar" controller. Various studies assist in arriving at this assessment. For example, an indication⁽¹⁶⁾ is provided by the results of the combined efforts of System Research and Development Service (SRDS), Transportation Systems Center (TSC), and National Aviation Facilities Experimental Center (NAFEC) in a test program aimed at examining the controller/computer interface with an air/ground data link. These results showed that if all the aircraft in the airspace were provided with a data link, the controller's message transaction times could decrease by as much as 57%. The study also shows that the data link would produce significant improvements in the precision and timeliness of message delivery.

A second indication⁽¹⁷⁾ is provided by the results of another man/machine interface study performed by NAFEC. This study shows that the automation of speed, heading, and altitude commands could result in significant reductions both in keyboard entry and communications workload. The reduction in the time spent in voice contact with the controlled aircraft amounted to as much as 63%. Also, the reduction in keyboard entries was as high as 34%.

These indications, although limited in their applicability to the specific situations of the test environment and test limitations, nevertheless provide a strong evidence that advanced automation will impact controllers communication workload. Additionally, the automation of message generation and routine planning will impact the strategic (planning) as well as the tactical conflict prediction and resolution workload. The overall impact on workload reduction could be summarized as follows:

- Substantial reduction in air-ground-air voice communications.
- Substantial reduction in planning workload.
- Substantial reduction in conflict prediction/resolution workload.

Furthermore, there are indications based on experience obtained in operating the Back Up Interceptor Control (BUIC) III system that the radar controller would be spending most of his time in surveillance and monitoring.

The reduction in workload associated with communications, planning and conflict prediction and resolution provides the potential for a reduction in the number of controllers and thus for increasing controller productivity in the ATC system, especially if the controlled airspace can be reorganized so that the en route sector controllers could handle more traffic.

Based on the NAFEC/TSC data link experiments⁽¹⁶⁾ which indicate a 57% reduction in control message transaction times and based on the MITRE/NAFEC experiments⁽¹⁷⁾ which indicate a 63% reduction in the time spent in voice contact with the controlled aircraft and a 34% reduction in keyboard entries, it is assumed here that a reduction in workload of 70% in communications planning, and conflict prediction and resolution could be achieved with proper and careful design of the different features of the Advanced ATC system.

Based on this reduction factor, the workload needed for the performance of all but the monitoring and surveillance functions would be about 19.6 man minutes per hour. Now, based on the indication by the BUIC experience that the radar controller spends most of his time in surveillance and monitoring, it is assumed that the latter function requires approximately 20 man minutes per hour. This is a conservative assumption since this workload corresponds to about one-half of all the workload components combined.

The distribution of workload in the data link era would be as is shown in Table 5-2. Comparing the total sector workload for the two pre- and post-data link eras shows that a controller productivity of 1.62 could be achieved due to the implementation of the data link. A summary of the controller productivity of the en route system in both the pre-data link and the data link eras are shown in Table 5-3.

TABLE 5-2
ESTIMATED PRODUCTIVITY IMPACT OF ADVANCED AUTOMATION
(DATA LINK ERA)

FUNCTION	WORKLOAD REDUCTION FACTOR	MAN-MINUTES PER HOUR	
		PRE	POST
COMMUNICATIONS	70%	22.4	6.7
CONFLICT PREDICTION/ RESOLUTION	70%	8.3	2.5
SURVEILLANCE/MONITORING	-	10.7	20.0
MANUAL CONSOLE OPERATIONS	0	5.0	5.0
PLANNING	70%	18	5.4
TOTAL		64.4	39.6
PRODUCTIVITY		1	1.62

TABLE 5-3
PRODUCTIVITY IN EN ROUTE SYSTEM

ERA	PRODUCTIVITY IMPACT/ POTENTIAL
PRE-DATA LINK	1.35
DATA LINK	1.62
TOTAL	2.19

6. STAFFING COSTS

6.1 Terminal Staffing Costs

Without Advanced Automation, the controller staff required to operate the Terminal System would grow by 9,500 controllers from about 13,500 to about 23,000 between the years 1985 and 2000 -- a growth of about 70%. This growth rate would be obtained after implementing the pre-data link improvements discussed in Part I of this report, and it is a reflection of the traffic growth in that time period. Of these additional controllers, 5,500 would be required in the non-ARTS-III terminal facilities, and the remaining 4,000 controllers would be added to the staff of the ARTS-III terminals. As discussed in Section 4, it is the latter portion of the terminal system that is the object of the Advanced Automation improvements. The growth in non-ARTS-III terminal staff would continue unaffected by automation as is shown in Figure 6-1, while with Advanced Automation, the growth in the ARTS-III terminal staff could be restrained. In order to assess this restraint, one has to assume an implementation schedule for the enhancements of the data link era; the schedule shown here in Figure 6-2 represents the best current estimate by the FAA Office of Systems Engineering Management. The figure shows that the first site and the last site would be implemented around 1984 and 1988, respectively.

Experience makes it prudent to assume, as the schedule shows, that the full benefits of automation will not be realized until two years after the implementation of the last site. It is also assumed here that the productivity due to Advanced Automation increases linearly from unity in 1984 to its full value of 1.30 by 1990. These assumptions are incorporated into Figure 6-3 which shows the average "weighted" controller productivity for the terminal system as a function of time. The productivity of both ARTS-III and non-ARTS-III terminals in both the pre-data link and data link eras are shown. The average productivity for the ARTS-III terminals due to improvements in the pre-data link era increases from 1 to 1.32 between 1980 and 1985. The average productivity of non-ARTS-III terminals increases from 1 to 1.05 during the same period. (For more details on the pre-data link era improvements, see Part I of this report.)

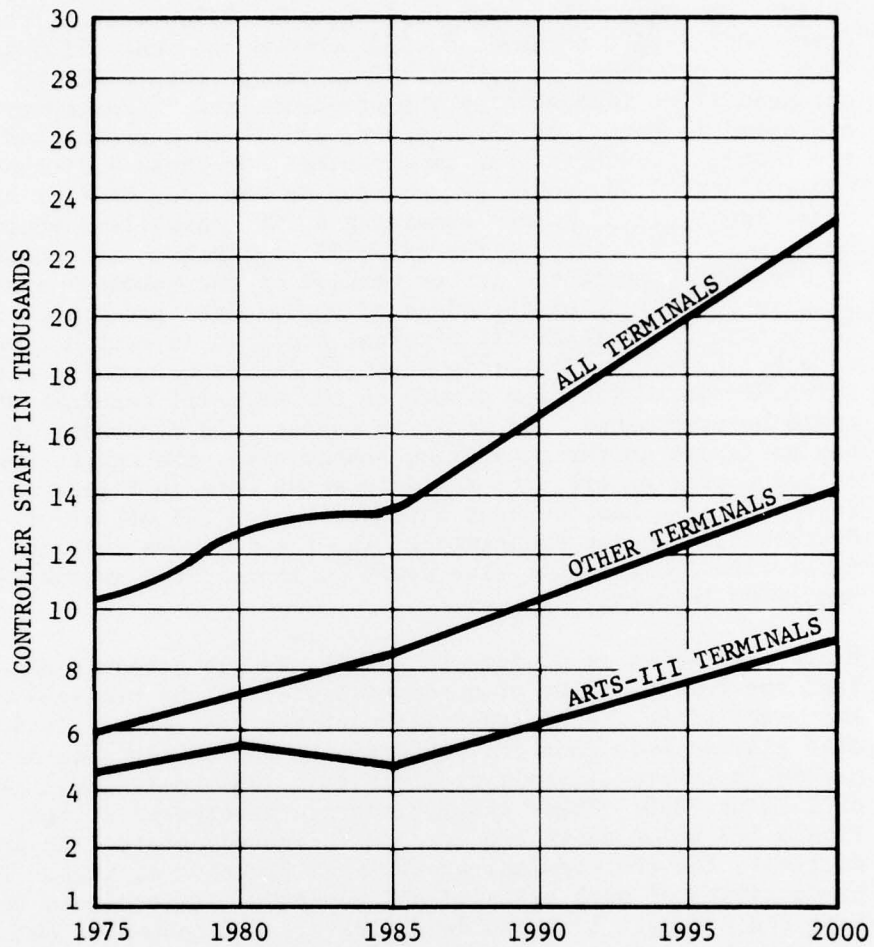
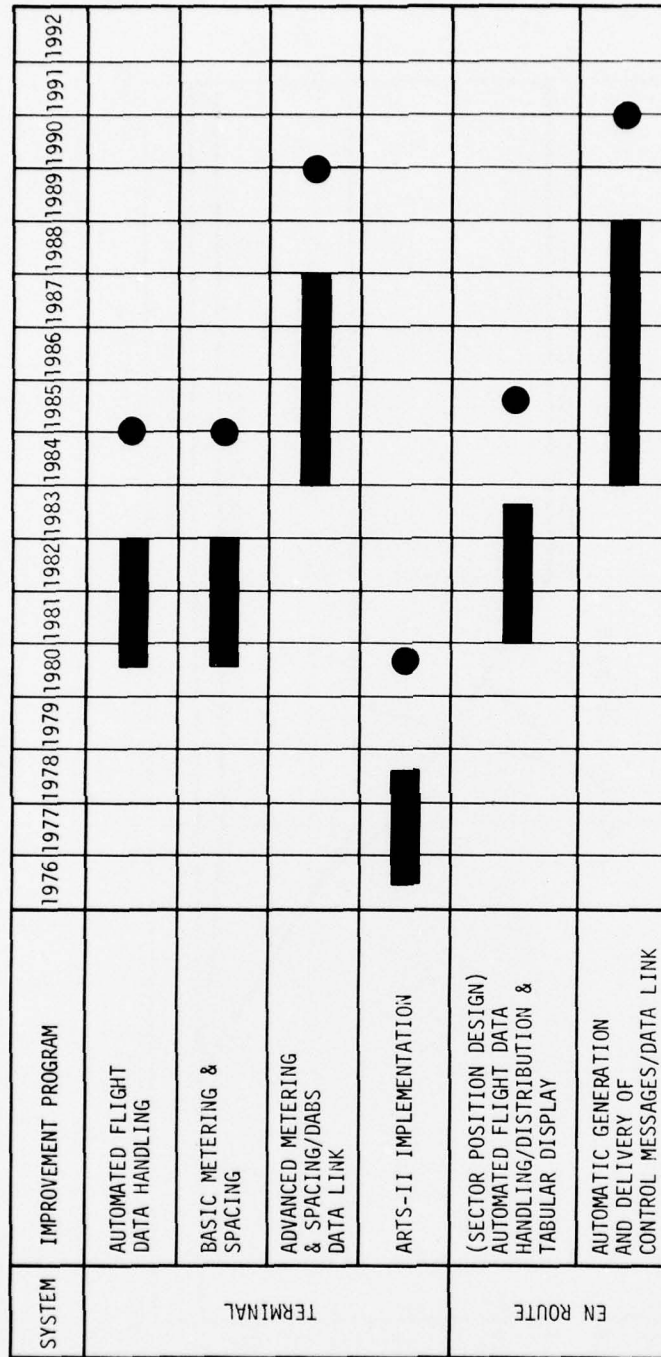


FIGURE 6-1
STAFFING REQUIRED IN TERMINAL ATC FACILITIES ASSUMING
UG3RD PRE-DATA LINK IMPROVEMENTS



● FULL BENEFITS REALIZABLE



FIGURE 6-2
ESTIMATED SCHEDULE OF UG3RD IMPROVEMENT PROGRAMS THAT IMPACT PRODUCTIVITY

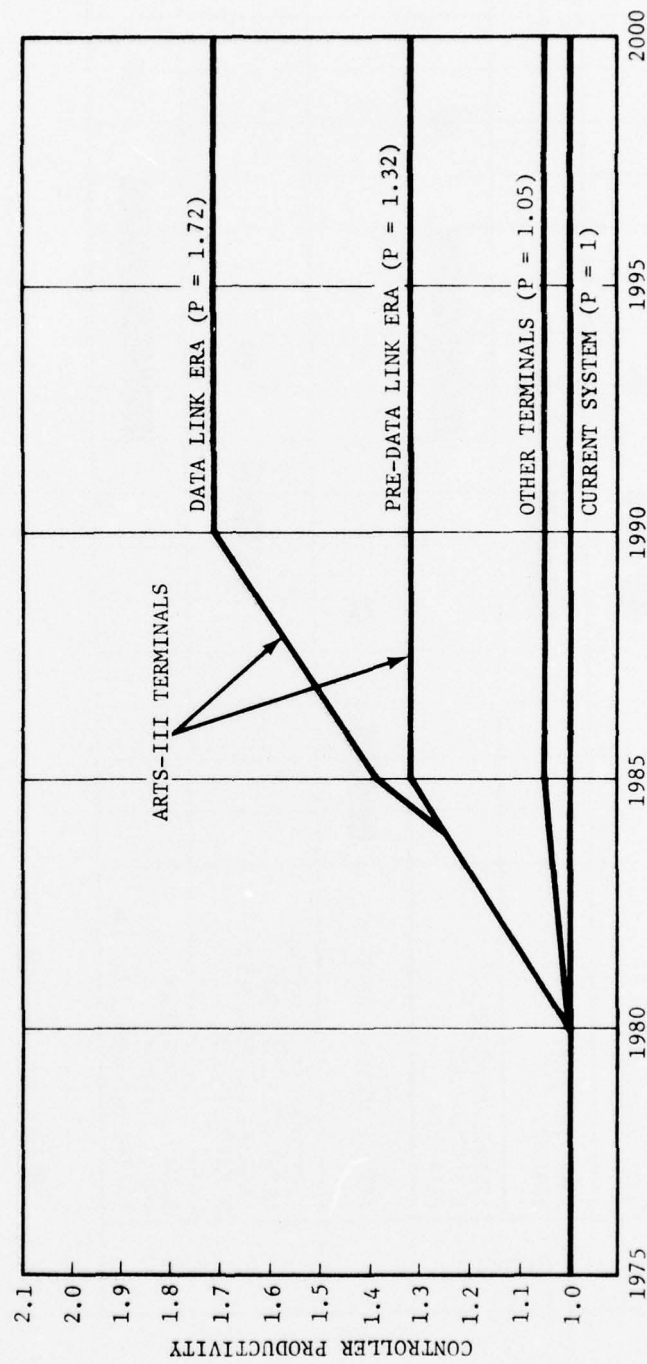


FIGURE 6-3
AVERAGE "WEIGHTED" CONTROLLER PRODUCTIVITY
IN TERMINAL SYSTEM

In summary, Figure 6-3 shows that the overall productivity gain in the ARTS-III terminal system due to improvements of both eras over the ten year period 1980-1990 should increase at the aggregate rate of about 5.5% per year from unity in 1980 to 1.72 in 1990. The terminal staffing prior to 1984 is the same as calculated in Part I and was shown in Figure 6-1. Beyond 1984, the staffing is calculated by dividing the pre-data link staffing requirements of Figure 6-1 by the productivity gain between the two systems: post-data link and pre-data link. The results are shown in Figure 6-4. Only the staffing in ARTS-III terminals is affected by automation. Also shown in Figure 6-4 are the staffing requirements for the non-ARTS-III terminals and for the whole terminal system.

By the end of the century, the staff requirement for the ARTS-III system would be reduced from 9000 to 7000 controllers. The savings in staff, due to Advanced Automation, would be about 22,000 man-years corresponding to a 1975 dollar cost in excess of half a billion dollars (see Figure 6-5). These savings are contingent upon the successful achievement of goals of E&D programs and achievement of implementation schedules.

6.2 En Route System Staffing Costs

Assuming the improvements in the pre-data link era were implemented and the productivity benefits attributable to them realized, the growth in staffing requirements of the en route system would be as is shown in Figure 6-6. The figure shows that the staffing requirements without Advanced Automation grow from 12,000 by 1985 to 21,000 by the end of the century. This growth would be substantially reduced with the implementation of Advanced Automation since it was shown in Section 5 of this report that the full productivity gain the data link era would be 2.19 over the baseline system and 1.62 over the pre-data link system.

Figure 6-2 shows that the implementation of Advanced Automation in the first site and the last site are 1984 and 1988, with a two year period beyond the latter for the realization of the full productivity benefits. Assuming a linear increase in productivity from 1984 to 1990 yields the overall productivity picture shown in Figure 6-7. The annual increase in controller productivity in the en route system is expected to be about 8% per year in the decade between 1980 and 1990.

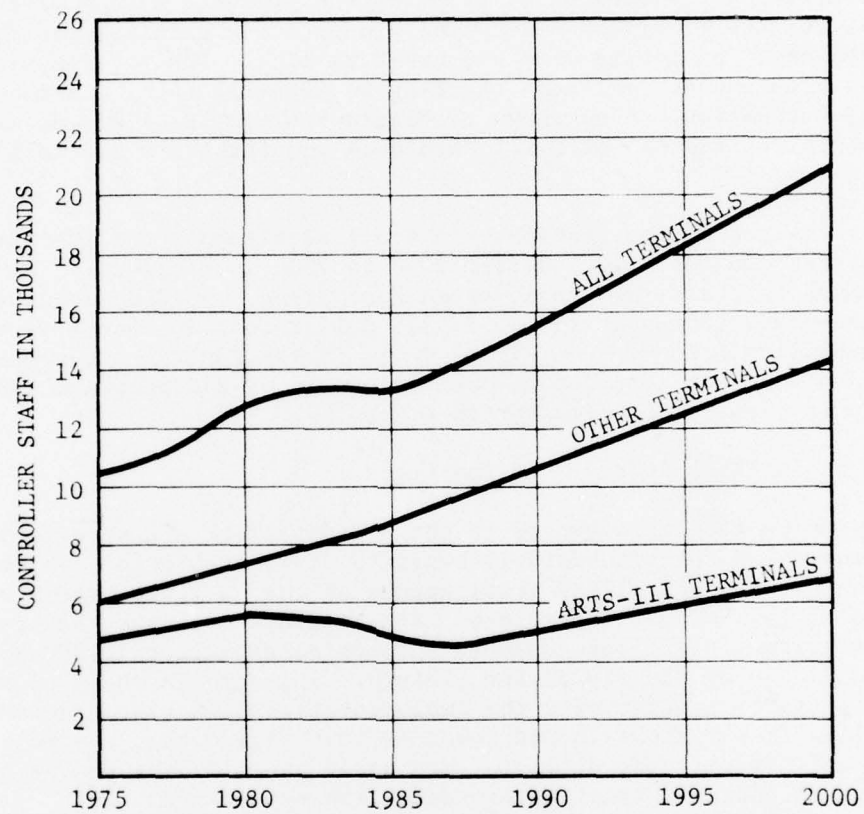
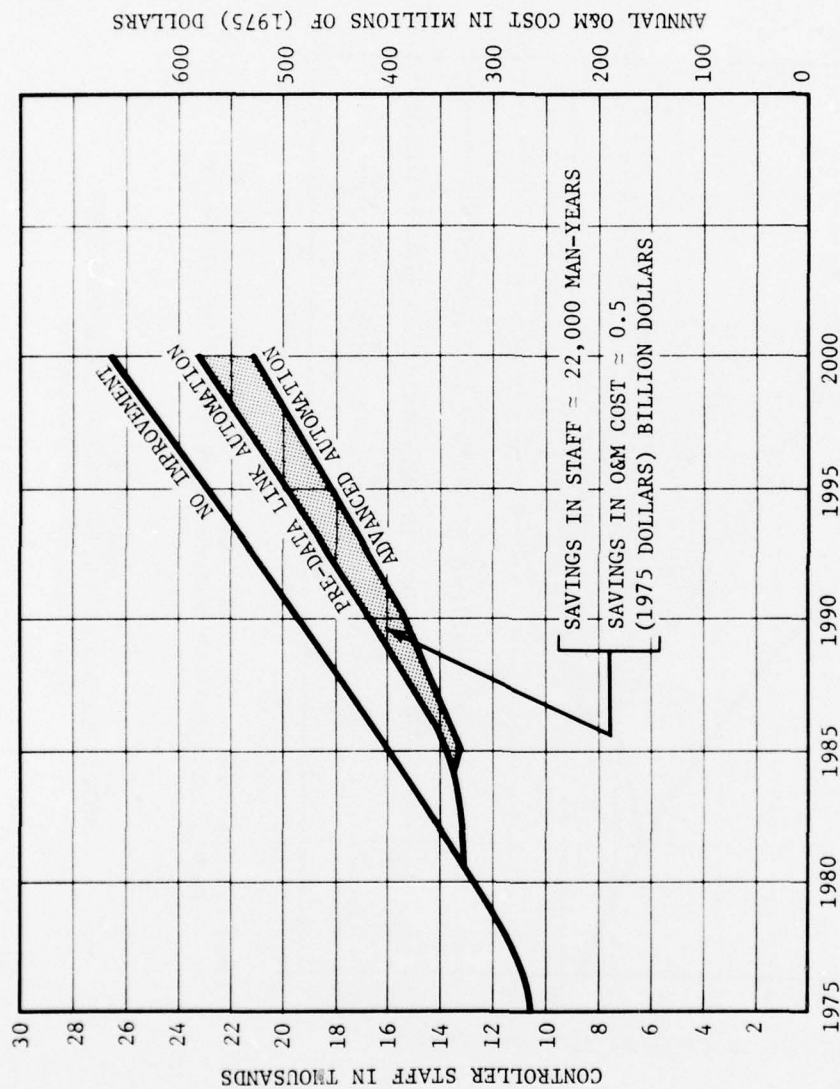
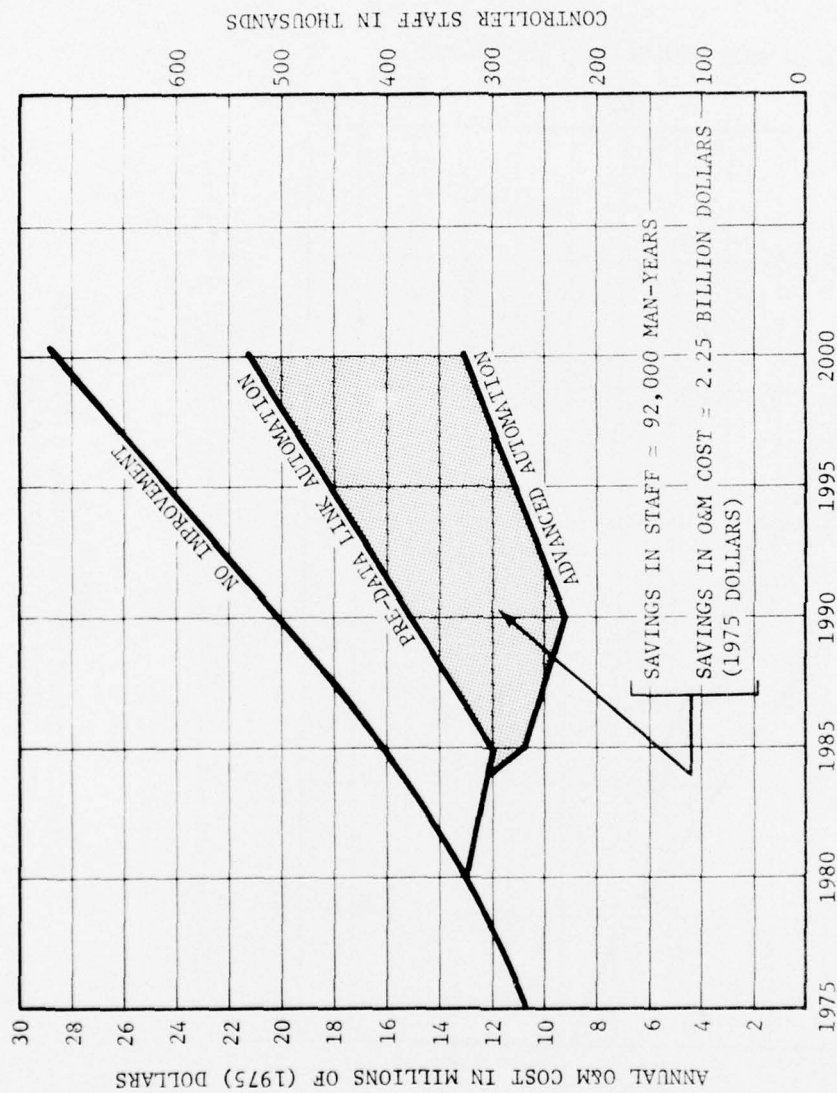


FIGURE 6-4
STAFFING REQUIRED IN TERMINAL ATC FACILITIES
ASSUMING ADVANCED AUTOMATION



NOTE: Savings contingent on successful achievement of goals of E&D programs and achievement of implementation schedules.

FIGURE 6-5
POTENTIAL SAVINGS IN TERMINAL SYSTEM O&M
COST DUE TO UG3RD IMPROVEMENTS



NOTE: Savings contingent on successful achievement of goals of E&D programs and achievement of implementation schedules.

FIGURE 6-6
POTENTIAL SAVINGS IN EN ROUTE SYSTEM O&M COST
DUE TO UC3RD IMPROVEMENTS

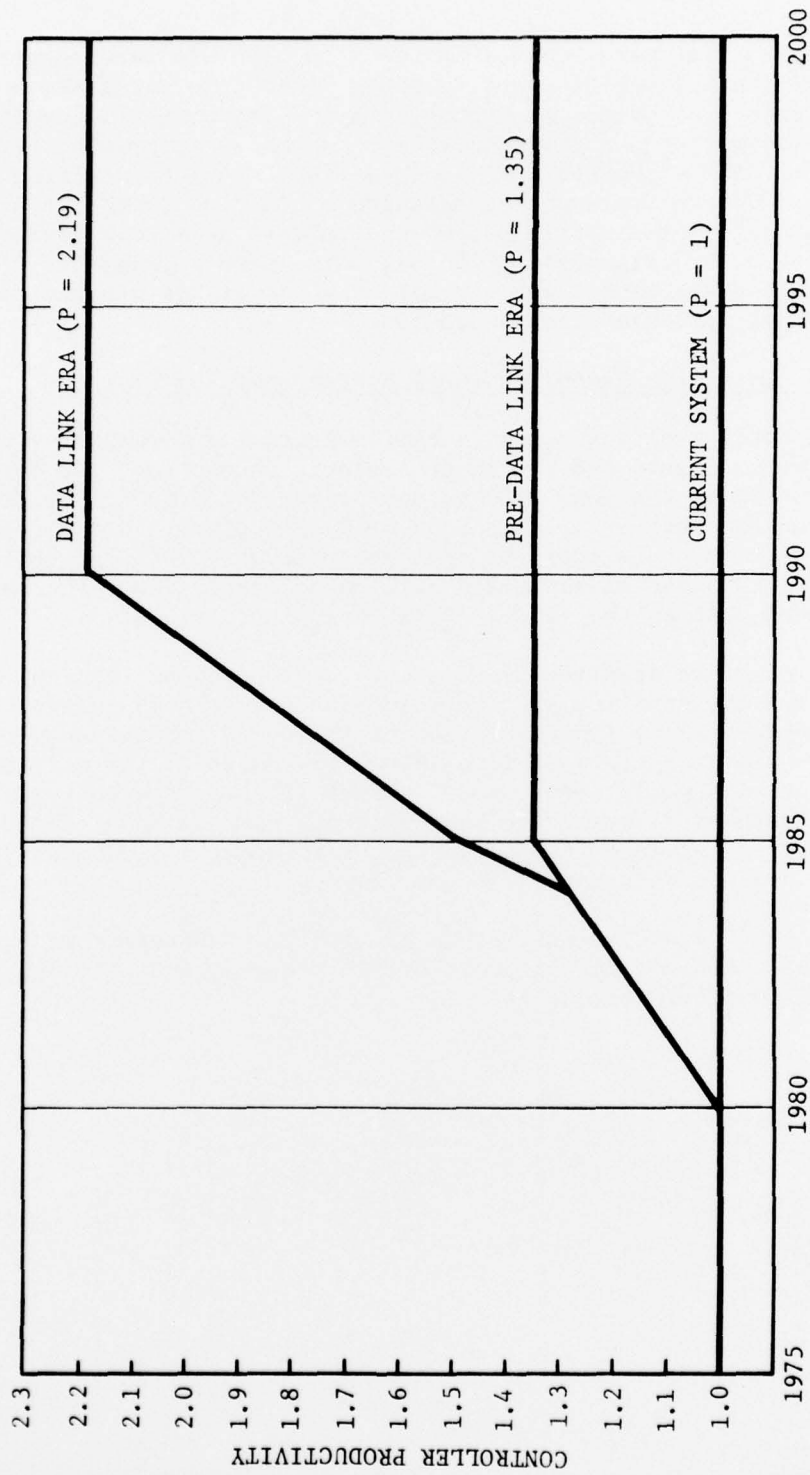


FIGURE 6-7
PRODUCTIVITY IN EN ROUTE SYSTEM

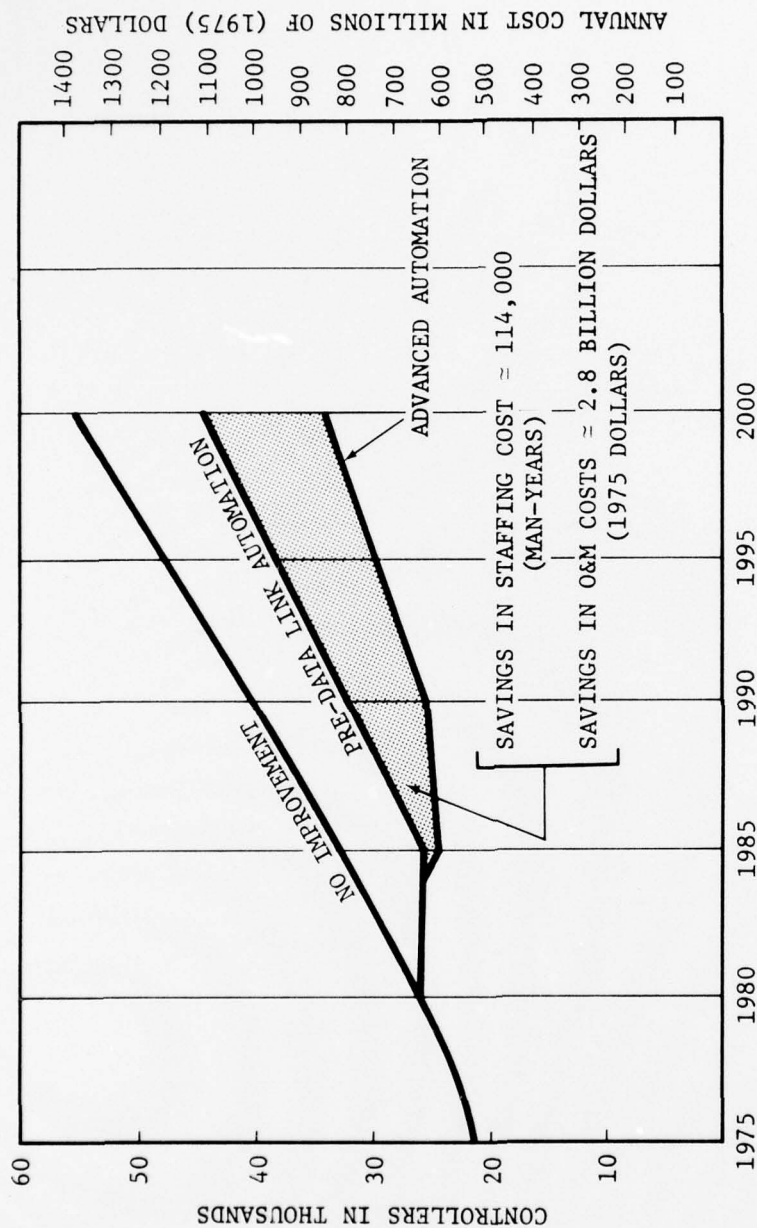
The staffing requirements in the data link era were obtained by dividing the staffing requirements without Advanced Automation (Figure 6-6) by the productivity gain between the two systems: a system with and a system without Advanced Automation (Figure 6-7). The potential savings (see Figure 6-6) in staffing requirements, due to implementing Advanced Automation in the En Route System, are approximately 92,000 controllers at a cost savings of about 2.25 billions of 1975 dollars. These savings are contingent upon the successful achievement of goals of E&D programs and achievement of implementation schedules.

6.3 Total (En Route Terminal) System Staffing Costs

The total staffing costs in the en route and terminal systems are shown in Figure 6-8. Without Advanced Automation, the total staff required by the year 2000 is approximately 45,000 controllers at an annual cost of 1.1 billions of 1975 dollars. With Advanced Automation, this could be reduced to about 34,000 controllers at an annual cost of about 840 million dollars. Thus, the savings in annual cost by the year 2000 is approximately 25%.

The combined staffing requirement (en route plus terminal) would extend the staffing plateau which would have been started around 1980 due to the implementation of the UG3RD improvements in the pre-data link era well into 1990. Beyond 1990, the staffing requirements would continue to increase in response to traffic growth although at a lower rate than possible without Advanced Automation. The total savings in staffing costs is about 114,000 man-years or 2.8 billion dollars (1975 dollars).

The savings estimated on this section are contingent on the successful achievement of goals of E&D programs and achievement of implementation schedules.



NOTE: Savings contingent on successful achievement of goals of E&D programs and achievement of implementation schedules.

FIGURE 6-8
TOTAL POTENTIAL SAVINGS IN EN ROUTE AND TERMINAL SYSTEMS
O&M COSTS DUE TO UG3RD IMPROVEMENTS

APPENDIX A

REFERENCES

1. "Aviation Forecasts, Fiscal Years 1976-1987," FAA-AVP-75-7, December 1975.
2. "IFR Aircraft Handled Forecast by ARTCC, Fiscal Years 1976-1987," FAA-AVP-75-11, October 1975.
3. Rucker, R. A., et al., "Controller Productivity Study," The MITRE Corporation, MTR-6110, Washington, D.C., November 1971.
4. "Review of the UG3RD ATC System Development," a Department of Transportation Staff Study, August 1974.
5. Keblawi, F. S., "Controller Productivity in the Upgraded Third Generation Air Traffic Control System, Part I: Automation in the Pre-Data Link Era," The MITRE Corporation, FAA-EM-75-3, Washington, D.C., July 1976.
6. "Engineering and Development Program Plan - Terminal Tower Control," FAA-ED-14-2, April 1973.
7. "The National Aviation System Plan, Fiscal Years 1976-1986," an FAA DOT Document 1000.27, Appendix 2, March 1975.
8. "Terminal Facility Configuration and Data Surveys," a series of NAFEC reports, FAA-NA-75-164, 166, 167.
9. Aviation Week and Space Technology, November 3, 1975.
10. "An Overview and Assessments of Plans and Programs for the Development of the Upgraded Third Generation Air Traffic Control System," FAA-EM-75-5, March 1975.
11. Flener, W. M., "ATC System Characteristics - A Forecast," paper delivered at Radio Technical Commission for Aeronautics, November 19, 1975.
12. Rucker, R. A., "Automated IFR Control: Project Overview and Objectives," The MITRE Corporation, FAA-EM-75-10, Washington, D.C., November 1975.

13. Bowers, A. W., "FY75 Status Report for the Automated IFR Traffic Control Project Front Royal Sector Model," The MITRE Corporation, MTR-7000, Washington, D.C., July 1975.
14. Horton, W. F., "Conflict Prediction Theory for Automated IFR Traffic Control," The MITRE Corporation, WP-10911, Washington, D.C., January 1975.
15. Rucker, R. A., "Advanced ATC Automation: The Role of the Human in a Fully Automated System," The MITRE Corporation, M75-39, Washington, D.C., May 1975.
16. Weisman, R., et al., "The Controller/Computer Interface with an Air/Ground Data Link," The Federal Aviation Administration, FAA-RD-75-133-2, Washington, D. C.
17. Ball, R. W., et al., "NAS En Route Control Message Automation Package 1 Final Test Report," The MITRE Corporation, MTR-7086, Washington, D.C., November 1975.

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